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STUDY OF THE EFFECTIVENESS OF REDUCED VISIBILITY GUIDANCE TECHNIQUES

Vol. I. Final Report

February 1979
Final Report

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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington, D. C. 20590

FOREWORD

This report contains a detailed description of research performed to evaluate the effectiveness of various techniques for guiding motorists during reduced visibility conditions such as fog, dust, or blowing snow. The report will be of interest to traffic operations and safety researchers concerned with problems caused by adverse weather conditions.

As a result of this research, a methodology was developed to assist highway engineers in allocating resources in a systematic way based on specific local highway and weather situations. The methodology is available in FHWA Implementation Package 79-2, "User Guidelines for Reduced Visibility System Design."

Research in reduced visibility guidance techniques is included in the Federally Coordinated Program of Highway Research and Development as Task 4, Project 1L, "Improved Traffic Operations During Adverse Environmental Conditions." Mr. Richard N. Schwab is the Project Manager.

Single copies of the report are available on request.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

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16. Abstract

A study was performed to evaluate the effectiveness of reduced visibility guidance systems and operating strategies; and determine, if possible, which factors of system design contributed to system effectiveness and which approach is economically feasible for a specific highway condition. Data were assembled and analyzed from seven existing reduced visibility systems. A utility/cost model was generated which permits quantitative comparisons to be made between systems. A "measure of need" index was generated to make comparisons between the seriousness of the hazard at different locations.

The study resulted in a methodology which allows a reduced visibility problem to be quantified and permits resources to be allocated in a systematic way in proportion to the seriousness of the hazard. The methodology has been separately published by the FHWA as Implementation Package Number 79-2.

This is the first of two volumes which constitute the final report. It is the Final Study Report, and contains a summary of pertinent literature. Volume II of the report is titled "Equipment Survey," and is identified as follows:

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PREFACE

The study described in this report was conducted by Sperry Systems Management (SSM), a division of Sperry Rand Corporation, under Federal Highway Administration (FHWA) contract DOT-FH-9189. Messrs. John Petrykanyn and William Heiss were Co-principal Investigators for SSM. Mr. Richard N. Schwab was the Contract Manager for FHWA and Mr. Luther McCollum was the Contract Officer for FHWA.

This report, in two volumes, describes all of the work accomplished during the course of the contract.

The first volume (Final Report) contains task-by-task descriptions of the study content. Each task is identified, the approach is described, and the findings are discussed.

This volume also contains a Literature Summary, which lists abstracts and listings prepared during the course of a search of the literature on reduced visibility topics.

The second volume is an Equipment Summary. It contains descriptions, performance details and costs for equipment used in reduced visibility environments.

The authors wish to acknowledge gratefully the support and advice provided by the Contract Manager, Mr. Richard N. Schwab.

The authors also wish to thank the members of the Reduced Visibility Task Force, who cooperated wholeheartedly in the assembling of data and provided invaluable guidance to the study effort, and the Federal Highway Administration's Regional Offices for their cooperation in providing additional data on reduced visibility locations.

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Section 1
OVERVIEW

1-1 INTRODUCTION

This study was sponsored by the Federal Highway Administration of the U.S. Department of Transportation out of a desire to evaluate the effectiveness of reduced visibility guidance systems and to disseminate the operational experience of agencies which have already dealt with the reduced visibility problem.

The study was conducted with the aid of a special Research Task Force composed of research and operations personnel from facilities which have reduced visibility guidance systems. They were located in the following states:

- Arizona
- California
- New Jersey
- Oregon
- Pennsylvania
- Virginia
- Wyoming.

The role of the Task Force was to review and guide study progress, keeping in mind the needs of operating facilities, and to provide data for evaluation purposes.

1-2 STUDY OBJECTIVES

The first study objective was to survey the existing reduced visibility systems in operation within the U.S. at the present time and to select a representative group of them for careful evaluation.

The evaluation was to shed light, if possible, on which factors of system design or maintenance or operation contributed to system effectiveness and which factors tended to limit effectiveness. Costs were to be considered in relation to the system effectiveness.

A second major objective was to produce a set of Guidelines for individuals with interests in the field of reduced visibility system design and implementation. The Guidelines were to use the results of the experience gained in evaluation to provide a

methodology for analyzing a reduced visibility problem and determining the need for a system. They were also to provide the user with a methodology for selecting a system suitable to the nature of the problem.

A third objective was to document the state of the art in the reduced visibility systems field: in terms of pertinent literature related to reduced visibility problems, and in terms of equipment technology and operational system experience.

1-3 STUDY HIGHLIGHTS

a. METHODOLOGY

The most important outcome of the study has been a methodology which allows a reduced visibility problem to be quantified and permits resources to be allocated in a systematic way in proportion to the seriousness of the need.

The process does not eliminate the need for judgment on the part of the user, nor should it do so. It provides a framework within which judgment can be exercised and helps to focus attention on the important features of the problem and on the availability and assignment of resources.

There are three major elements to the methodology. The first is a "measure of need" (MON), which is a number, on a scale of 1 to 100, describing the seriousness of the reduced visibility hazard.

The second element is a set of coded answers to specific questions that were carefully designed to reflect accurately the user's problem area characteristics. This serves to guide the user in configuring candidate systems which are suited to the nature of the problem.

The third element is a utility model which assigns a numerical utility to each part of the system configuration. When used in conjunction with estimated system cost, it is a tool to help the user select a system which gives the greatest return per dollar spent.

The following paragraphs discuss these three major elements of the methodology.

b. MEASURE-OF-NEED

The measure-of-need is computed from data which are assembled by the user for the problem area. The data include:

- Fatalities resulting from accidents traceable to reduced visibility conditions
- Multiple vehicle collisions traceable to reduced visibility conditions
- Total accidents traceable to reduced visibility conditions
- Average annual daily traffic (AADT) volume

- Frequency of days on which reduced visibility occurs
- Number of exit and entrance ramps
- Horizontal curvature, vertical curvature, and grade indices

The MON can be interpreted as a measure of the required sophistication and density of system functional elements or as a measure of how badly the system is needed.

c. PROBLEM CHARACTERISTICS

The problem characteristics consist of a set of fourteen key factors which determine the nature of the functions which the system must perform. There are eleven factors directly related to the reduced visibility problem:

- AADT category
- Size (length)
- Frequency of patrol
- Feasibility of roadway closure or diversion
- Intensity of reduced visibility problem
- Existence of a reduced visibility problem during daylight
- Predictability of location
- Predictability of time
- Existence of a significant fraction of transient drivers
- Importance of speed uniformity
- Existence of other weather problems

There are also three factors which are important because solutions to the problems which they pose contribute to solutions to the reduced visibility problem. These are:

- Need for automatic traffic congestion or incident monitoring
- Need for automatic traffic control during special events
- Need for automatic traffic control during construction or maintenance operations

The description of a problem area embodied in this set of characteristics enables the user to arrive at a suitable system configuration by means of an unambiguous, step-by-step process which is fully described in the Guidelines.

d. UTILITY/COST

The utility/cost ratio provides a means for comparing various system configurations. The numerator of the utility/cost ratio is a number derived from a utility model. The model is composed of several factors which describe the usefulness of a reduced visibility system. Each factor has assigned to it a weight which is in proportion to its importance in relation to the other factors. The denominator of the utility/cost ratio is the present worth of the system.

e. USER GUIDELINES

The Guidelines provide the system planner with a step-by-step procedure for determining how badly a system is needed, for configuring potential solutions, and for selecting between candidates on the basis of cost and utility. A simplified flow chart of this procedure is shown in Figure 1.

Users whose problems do not require sophisticated treatment will find that the procedure is designed to circumvent those parts of the Guidelines which deal with the more complex systems.

1-4 OTHER STUDY HIGHLIGHTS

In addition to the major conclusions above, several other conclusions concerning the broad aspects of reduced visibility were arrived at during the course of this study.

a. Most important was the conclusion that the availability and accuracy of data on the location, duration and intensity of reduced visibility conditions is limited, even in locations where systems have been installed.

The primary reason for this situation is the lack of inexpensive reliable automatic instruments which makes it necessary to rely on direct observation for the most part. Most reduced visibility sensor design to date reflects the airport-oriented origins of the instruments rather than traffic-related needs.

Gradually, this picture is changing. Cheaper, smaller and more flexible reduced visibility detectors have recently become available, partly as a result of the introduction of solid state electronics techniques.

However, even these instruments are far from being inexpensive enough to consider using for the purpose of identifying problem areas. It is, therefore, suggested that research be directed toward the acceleration of this trend.

The development of such instrumentation would have double benefits; first, it would simplify, shorten, and improve the system design process. Second, it would make implementation less costly and more effective.

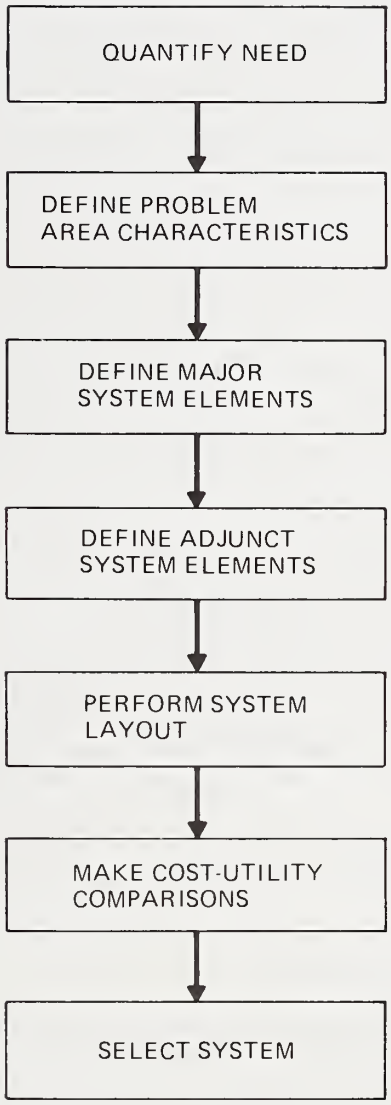


Figure 1. Simplified Flow Chart of Guidelines Procedure

b. Another conclusion reached during the evaluation process was that in some cases the limiting factor in system effectiveness is not equipment capability, but an implementation or maintenance philosophy which does not take into account the integrated behavior of electronic systems. Divided responsibility for maintenance is one example; failure to appreciate the system implications inherent in the modification of key electronic elements of the system is another.

When the system is a simple one, this is often not prejudicial to effective operation, but it becomes an important factor in more sophisticated systems with many interfacing functional elements.

c. Finally, it was the conclusion of this study that very large and sophisticated highway traffic control systems cannot be justified on the basis of reduced visibility alone, primarily because reduced visibility accidents, despite their sometimes spectacular nature are very rare events. Such systems are usually built to cope with recurring and often dangerous situations arising from daily congestion, rather than occasional events.

However, many of the elements of a system designed for vehicle surveillance and control during congestion are also required for reduced visibility guidance. It is therefore cost-effective to add the reduced visibility guidance function to the system early in the planning stage, if such a function is at all necessary.

1-5 DESCRIPTION OF REPORT

The study resulted in a two volume Final Report, of which the present document is the first volume.

Volume I: Final Study Report

This volume contains the description of, approach to, and findings of the eight tasks which constituted the study program. It also contains a summary of the results of the economic evaluation of several reduced visibility systems.

Volume I also includes, as an appendix, abstracted and cross-referenced results of a survey of the available technical literature on reduced visibility problems, equipment and systems.

Volume II: Equipment Survey

This volume contains extensive descriptions, cost information, user experience and lists of manufacturers of reduced visibility equipment, separated by type.

In addition, a set of User Guidelines (Reference 1) was prepared with the reduced visibility system designer or operations planner in mind. These contain step-by-step procedures to determine the need for a system, configure candidates, determine their costs and utilities, and select between them. The guidelines also contain a short overview of reduced visibility equipment types, and a pictorial summary of several existing operational reduced visibility systems.

Section 2
RESEARCH APPROACH

2-1 STUDY OBJECTIVES

The objectives of this Study were to:

- Examine a broad spectrum of reduced visibility guidance (RVG) systems and operating strategies
- Evaluate their effectiveness
- Determine the most economically desirable approach for specific reduced visibility (RV) conditions
- Produce a comprehensive set of guidelines for potential users, encompassing past experience and recommending solutions for specific problems

To accomplish these objectives, seven tasks were defined:

a. TASK A

Establish a Research Task Force to guide and inform study progress and review results.

b. TASKS B, C, D

Conduct surveys of the literature, equipment-state of the art, and of operational system experience in the reduced visibility area.

c. TASKS E, F

Select and evaluate representative systems.

d. TASK G

Define system configurations for specific reduced visibility conditions.

e. TASK H

Prepare User Guidelines.

The interrelation between tasks is shown in Figure 2, and each of these tasks is discussed in the appropriate sections that follow.

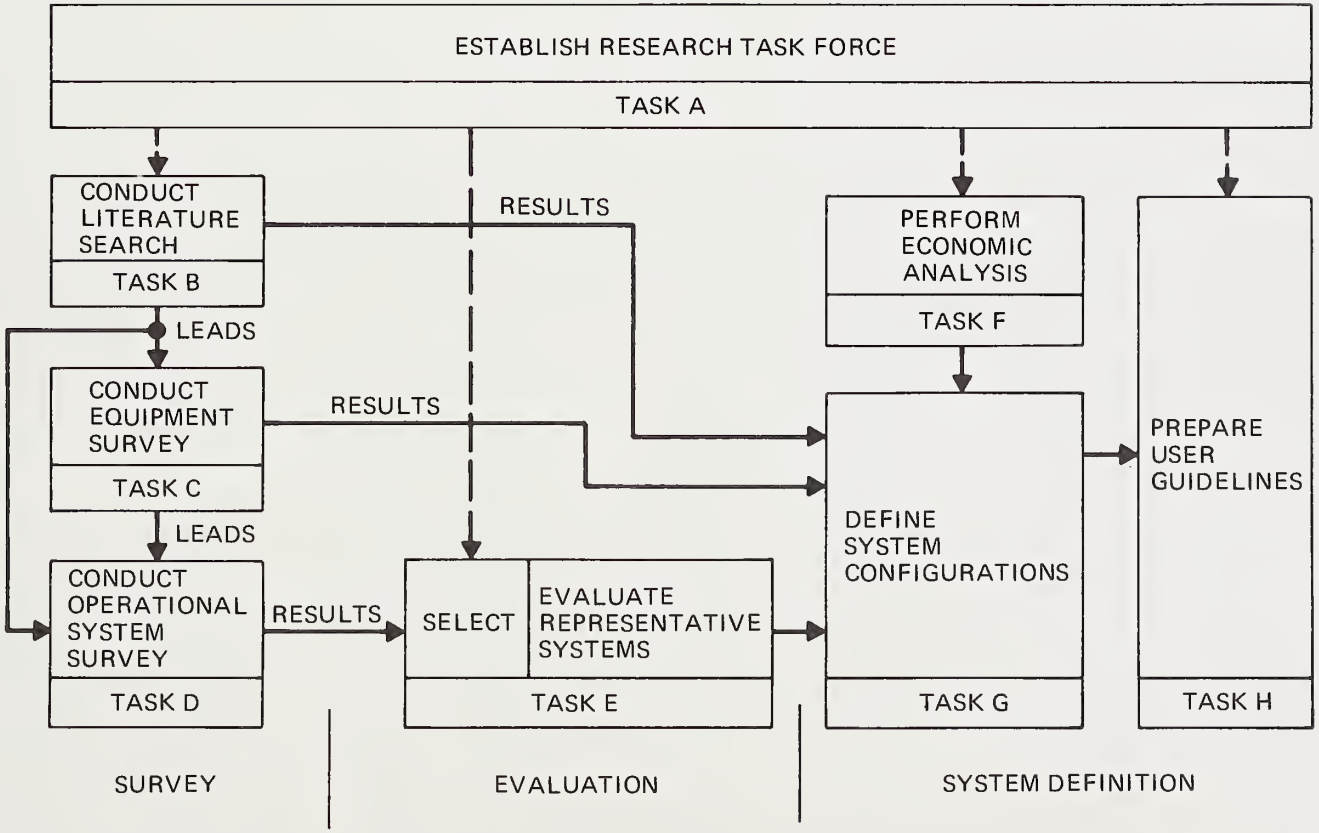


Figure 2. Project Task Summary

Section 3
STUDY RESEARCH BY TASKS

3-1 TASK A: ESTABLISH RESEARCH TASK FORCE

a. TASK FORCE OBJECTIVES

Very early in the study program, a Task Force was assembled from agencies and states which are confronted with reduced visibility problems and which either currently employ or have recently evaluated reduced visibility systems.

The objectives of the Task Force were, generally speaking, to guide and review progress of this study and to provide access to and experience with operational RVG systems.

Seven agencies agreed to serve on the Task Force. They are listed as follows:

Agency	Task Force Representative
Arizona Department of Transportation	Carlie Bowmer
California Department of Transportation	Edward J. Tye
New Jersey Turnpike Authority	Robert F. Dale
Oregon Department of Transportation	Dwayne Hofstetter
Pennsylvania Department of Transportation	Louis Schultz
Virginia Highway Research Council	Frank D. Shepard
Wyoming Highway Department	Anthony J. Schepp

In addition, the Task Force included the Federal Highway Administration Contract Manager, Richard N. Schwab.

b. TASK FORCE FUNCTIONS

In pursuit of the objectives named above, the Reduced Visibility Task Force carried out a variety of activities which are identified in Table 1 by the study task to which they are most closely linked.

TABLE 1. TASK FORCE FUNCTIONS

Study Task	Task Force Functions
A. Establishment of Research Task Force and Task Force Meetings	a) Respond to solicitations of interest and provide requested information to determine candidacy for Task Force members
	b) Participate in establishment of working procedures for communicating, reviewing, information and provide inputs to decisions
	c) Attend Task Force Meetings
	d) Review and comment on Interim Report
B. Literature Search	a) Provide current inputs on their agency's system as well as any pertinent available information on other systems
	b) Review and comment on list of references assembled by research team
C. Equipment Survey	a) Provide operating experience information on equipments used in their agency's system
	b) Review and comment on list of equipments and relevant data assembled by research team
	c) Review and comment on equipment criteria established by research team to evaluate equipments for RVG Systems
D. Survey Operational Systems	a) Provide inputs on their agency's system as well as any pertinent available information on other systems
	b) Review and comment on classification structure for systems from a user agency viewpoint

Table 1. Task Force Functions (Continued)

Study Task	Task Force Functions
E. Evaluation of Operational Systems	a) Review and comment on selection criteria established for sample systems to be evaluated b) Assist in the review and selection of candidate systems for evaluation c) Provide data, documentation, historical background, and operating experience information on their agency's system d) Review and comment on research team's data collection and system evaluation plan e) Provide recommendations for coordinating data collection activity with user agency's on-going data collection activities f) Assist in the gathering of on-site data by providing support in system operation, recording certain long-term data for use by the research team, and by participating in on-site experiments and measurements conducted by the research team g) Review and comment on the objectives and criteria established by the research team for the evaluation of the systems h) Provide guidance in the selection and weighting of criteria to be used in the evaluation of the systems in relation to the established objectives i) Review with the research team the results of the evaluation of operational systems and provide comments on results

Table 1. Task Force Functions (Continued)

Study Task	Task Force Functions
F. Economic Analysis	a) Review and comment on the cost-utility model developed by the research team
	b) Provide data on installation, operating and maintenance costs for their agency's system
	c) Provide recommendations on the selection and weighting of utility factors
	d) Provide recommendations and assistance in the assessment of predictability variables (location, frequency, severity, duration) and in the development of factors and formulas for treating these variables
	e) Review with the research team the results of the economic analysis and provide comments on results
G. Systems Definitions	a) Assist in the development of warrants and requirements for the minimum and higher capability systems
H. Guidelines for RVG System Users	a) Review and comment on format and content of guideline handbook from viewpoint of user agency

3-2 TASKS B, C, AND D: LITERATURE, EQUIPMENT AND OPERATION SYSTEM SURVEY

a. LITERATURE SURVEY

The literature survey consisted of a full scale literature search on reduced visibility detection and warning systems. The literature search was divided into two parts. Part I consisted of obtaining pertinent references from the files of the following organizations:

- Highway Research Information Service - HRIS (National Research Council, Washington, D.C.)

- National Technical Information Service - N.T.I. Search (U.S. Department of Commerce; Springfield, Virginia)
- National Highway Traffic Safety Administration (U.S. Department of Transportation, Washington, D.C.)
- National Safety Council Literature (SSM Search) (Chicago, Illinois)
- Smithsonian Science Information Exchange (Washington, D.C.)
- Franklin Institute Research Laboratories (Philadelphia, Pennsylvania)

Key work descriptors were supplied as part of the computerized retrieval strategy. A sampling of the code words used is as follows:

- Fog
- Snow
- Dust
- Rain
- Countermeasures
- Visibility
- Accident Prevention
- Traffic Safety
- Smoke
- Ice
- Frost
- Sand
- Reduced Visibility
- Vehicle Guidance Aids
- Detectors
- Warning Indicators
- Hazard Warning Display
- Cost/Benefit Analyses
- Remote Sensing
- Effectiveness Evaluation

The output document packages of the literature search were reviewed by the Task Force members in order to identify those references which would be of importance to the research project. Private communication with the study Task Force members, federal and state highway organizations were also used to identify other pertinent literature which did not appear in the formal literature search.

Part II of the literature search study consisted of acquiring the articles identified by the references and examining them for their usefulness to the project research objectives. A total of 81 reference documents were considered to be of primary importance. These documents were reviewed and the relevant information was digested and abstracted into a standard format. The digests of the primary references are presented in Appendix A of this volume. A table of contents and literature index is provided in which the references are identified under key words or phases arranged in alphabetical order. Document numbers were assigned to the primary literature digests to facilitate the use of this reference volume. References considered to be of secondary importance were not abstracted but only listed.

b. EQUIPMENT SURVEY

This survey covered five categories of equipment commonly found in reduced visibility guidance systems. These categories consist of:

- Reduced visibility sensors or monitors employing transmission, back scatter, forward scatter, local scatter, CCTV and optical contrast techniques
- Vehicle sensors employing loop, magnetic and magnetometer principles of operation
- Signs, including fixed message blankout, and variable message signs. Displays, including lamp matrix, disc matrix, neon, rotating drum and roller shade types
- Delineation, including passive and active techniques, such as thermoplastic striping, post delineation, raised pavement markers, pavement inset lights, and strobe lights
- Communications, including cable, radio and microwave techniques. This category includes highway advisory radio (HAR) aids.

The objectives of the equipment survey are to develop a framework within which various approaches to reduced visibility problems may be compared and evaluated. Specifically, the goal is to document for system planners the technological background, state of the art, cost and user experience of the equipment described in the survey.

The results of the Equipment Summary are presented in Volume II of this study report.

c. OPERATIONAL SYSTEM SURVEY

SSM conducted a survey of all State departments of transportation and related agencies such as turnpike and bridge and tunnel authorities. The objective was to compile a complete list of all operational reduced visibility systems in the United States, to facilitate the transfer of useful information in the field.

The results of the operational system survey were tabulated by State for easy reference. Each State reference chart provides a general description of reduced visibility problems in the State, followed by thumbnail sketches of the State's operational RVG systems. Each description is accompanied by the name and telephone number of the individual providing the system information, and gives the location, length, status, equipment type, system type and other pertinent system data.

The information gathered during the operational system survey is presented in Appendix A of the User Guidelines (Reference 1).

d. TASK FORCE MEETINGS

Four Task Force meetings were held during the study period. Each meeting consisted of a field trip to view the reduced visibility system of the host agency, followed by business associated with study progress.

3-3 TASK E AND F: SAMPLE SYSTEM EVALUATION AND ECONOMIC ANALYSIS

These tasks represent the evaluation portion of the study program which consists of a detailed study of a group of RVG systems. The systems were chosen so that the greatest possible breadth of options is represented, both in functional capability and in equipment. The evaluation period extended over approximately one year, allowing sufficient time to observe systems in different climate surroundings. In the following sections, the study approach to the sample system evaluation process is represented first, followed by the findings of the analyses which were performed.

a. APPROACH

The approach to the system evaluation and economic analysis tasks were comprised of several subtasks. These are:

- Select systems for study
- Prepare data collection and system evaluation plans
- Collect data and interview material
- Review system history and user experience
- Develop a methodology for determining the need for an RVG system and exercise on selected systems
- Develop a methodology for evaluation of system utility and exercise on selected systems
- Develop an approach to system cost estimation and exercise on the selected systems

The study approach used for each of the above subtasks is presented in the ensuing paragraphs.

1. Selection of Systems For Study

The systems selected for evaluation were chosen to provide data on as many reduced visibility conditions as possible (e.g., fog, blowing dust, blowing snow). Rain-caused problems are not within the scope of this study.

A preliminary list of candidate systems was presented to the Task Force at the second Task Force meeting in Cheyenne, Wyoming (February 8, 9, 1977), and

was approved by them with minor modification. The candidates were selected with several goals in mind; namely:

- Representation of as many different kinds of reduced visibility environments as possible (e.g., fog, dust, snow)
- Widely scattered geographic locations
- Ability to provide data on implementation, operation, maintenance and evaluation

The selected systems are shown in Table 2. They range from the simplest type of passive delineation and signing, typified by California's system, to the computerized detection and warning system on the New Jersey Turnpike.

Source of the systems were integrated from elements which could be considered in other combinations in addition to the implemented one. For example, Wyoming's system of snow fences, highway advisory radio broadcasts, and variable message signs could be analyzed from the point of view of snow fences alone, or fences in combination with variable message signs, or all three elements. Thus it was possible to examine more combinations than there were actual systems.

2. Preparation of Data Collection and System Evaluation Plans

(a) Data Collection Plan

A data collection plan was prepared for each system to be evaluated and distributed to the members of the Task Force early in the study program. The plan was composed of two parts: a general data requirements section, which was nearly identical for all systems to be evaluated; and a specific data collection plan directed towards systems which possessed unique features (such as Virginia's pavement inset lights).

The general data requirement section listed eleven categories of data. A typical example is shown for the case of Arizona in Appendix B.

The specific data requirement section of the data collection plan was tailored to the special features of the system on which data was desired. For example, the New Jersey Turnpike system offered the possibility of evaluating the following features (Appendix C):

- Use of vehicle detectors as a source of information with which to control VMS signs
- Comparison of visibility of neon and bulb matrix signs under clear and foggy conditions
- Use of vehicle detectors to study sign effectiveness

TABLE 2. SYSTEMS SELECTED FOR EVALUATION

State	Visibility Problem	Location	Length		Outstanding System Feature
			Miles	Km	
Wyoming	Blowing Snow	I-80 between Laramie & Walcott Junction	60.0	96.6	Snow fence
California	Fog	Route 91 between Corona & Riverside	20.0	32.2	Raised pavement reflectors
Virginia	Fog	I-64 near Staunton	5.8	9.3	Inset pavement lights
Arizona	Blowing dust	I-8, I-10 near Phoenix	82.0	131.9	Broadcast radio with VMS(1)
Oregon	Fog	I-5, near Albany	6.4	10.3	Vehicle detectors and VMS
Wyoming	Blowing snow	I-80 between Laramie & Walcott Junction	60.0	96.6	Computerized VMS and HAR(2)
New Jersey	Fog	NJTP between Interchange 9 & Interchange 18	46.4	74.7	Vehicle detectors, computerized VMS

(1)VMS - variable message sign
(2)HAR - highway advisory radio

Experiments were designed to obtain data on the latter two features and arrangements were made with Turnpike authorities to acquire the data when reduced visibility conditions were suitable.

Consideration was given to setting up semi-permanent data acquisition stations at some locations to obtain data on the effect of fog on driving behavior in the absence of signing (to determine whether or not driver speeds could be used for signing control). Research instruments such as the FHWA Traffic Evaluator System (TES) were considered, but the unpredictability of reduced visibility conditions made the use of the TES impractical.

(b) System Evaluation Plan

The evaluation of each system was accomplished by estimating compliance in the utility model (paragraph 3-3a. 6) on the basis of data acquired about the system. The compliance estimate was made by SSM, but an independent parallel compliance estimate was requested of the Task Force member in whose jurisdiction the system fell. All estimates were reviewed by the Task Force. The Task Force estimates provided information on the amount of variance to be expected in estimating compliances.

Although the estimation of compliance is subjective, the more quantitative the data that are available, the more accurate the estimate of compliance will be. This consideration was weighed against the cost and difficulty of acquiring some kinds of data. The approach taken here was to make maximum use of existing data in the form of reports and other easily accessible sources.

A sign effectiveness analysis was performed on the Oregon variable message signs using the vehicle detector output data gathered by the State during reduced visibility conditions. Two evaluation analyses were performed on the special features of the New Jersey Turnpike system. The first evaluation was concerned with comparing the visibility characteristics of the bulb matrix and neon tube signs during reduced visibility conditions. The second evaluation attempts to determine the effect of the NJTP speed limit/speed warning signs on driver behavior in a reduced visibility environment. The results of the Oregon and New Jersey Turnpike special feature evaluation studies were contained in Appendix C.

3. Collection of Data and Interview Material

Most data was assembled with the cooperation of the staffs of the systems being evaluated. In some cases, such as the New Jersey Turnpike data acquisition were carried out in cooperation with system operating personnel. In every case, interviews were conducted with system operation, maintenance, police patrol and research staffs. The interviews were designed to bring to light information pertinent to the evaluation but not included in the formal data requirements. Interviews were conducted with staffs of the following systems:

- Oregon
- Wyoming

- California
- Virginia
- Arizona
- New Jersey Turnpike

4. Review of History and User Experience

In some cases, evaluation of all or parts of systems had already been conducted by the states or agencies responsible for them. These were made available to SSM and were reviewed for data which might be pertinent to the evaluation process. User experience in some cases could be assessed from the results of motorist surveys or CB Monitoring surveys.

5. Measure-of-Need Methodology and Application To Task Force Systems

The objective of this part of the system evaluation task was to develop a quantitative measure of the need for a reduced visibility guidance (RVG) system in a given set of circumstances. After detailed analyses and consultation with the Task Force, the results of which are described in the following paragraphs, a methodology was developed which provides a quantitative estimate of the severity or "measure-of-need" (MON) for the employment of RV countermeasures.

The MON methodology was exercised on each of the systems selected for evaluation. It is also an important part of the User Guidelines, where it serves as the starting point for the process of fitting an RVG system to the user's environment.

(a) MON Methodology

The development of the MON methodology has undergone several iterations as a result of analysis of data collected from numerous roadways with RV problems and discussions with the members of the Task Force.

Initially, the measure of need formulation was to be based on a statistical assessment of reduced visibility system operations and environmental data. FHWA regions were asked to submit data from RV facilities or from sites where facilities did not exist, but where there were reduced visibility problems; preferably the latter.

For several reasons, the statistical approach was not used; primarily because most of the data received came from sites with systems in place at the time the data were collected. It was felt that this would tend to bias the parameters derived from the data. Another reason for rejecting the statistical approach was the lack of a sufficiently large sample population in some AADT categories.

In the final formulation, a MON is computed from the following equation:

$$MON = K_1C_{1N} + K_2C_{2N} + K_3C_{3N} + K_4C_{4N} + K_5C_{5N} + K_6C_{6N}$$

(b) General Description: MON Equation

The C's are called "Categorization Indices". They are computed from actual facility accident data, roadway volume and geometric data, and data which describes the frequency of the RV condition at the facility in question, as shown in Table 3. In addition to these data, which are derived from facility records, the C's are a function of certain parameters which in effect compare the magnitude of the individual facility data with the magnitude of the same kind of data from other locations with similar roadway traffic.

The K's are weighting factors that describe the relative importance of the categorization indices in their contribution to the total measure of need.

TABLE 3. DATA SOURCES FOR MON CATEGORIZATION INDICES

Categorization Index	Index is Computed From:
C_{1N}	RV accident fatalities due to reduced visibility
C_{2N}	Multiple vehicle collisions due to reduced visibility
C_{3N}	Total accidents due to reduced visibility
C_{4N}	Roadway AADT and number of reduced visibility day/yr.
C_{5N}	Number of entrance and exit ramps
C_{6N}	Roadway grade and vertical alignment

(c) Two Components of MON Equation

The MON equation is expressed in terms of two components as follows:

$$MON = MON_A + MON_P$$

where:

$$MON_A = K_1C_{1N} + K_2C_{2N} + K_3C_{3N} = \text{Accident Portion}$$

$$MON_P = K_4C_{4N} + K_5C_{5N} + K_5C_{5N} = \text{Potential Portion}$$

The reason for this method of presenting the MON is to account for the fact that a system may be necessary even in locations where no accidents have occurred, if the potential is great enough.

Reduced visibility accidents are rare events. Two roadways may have very similar geometrics, volumes and reduced visibility frequencies. One may have had a catastrophic reduced visibility accident while the other has not, particularly when the accident history for both facilities is compared over short time periods. The potential for such an accident may be inherent in both facilities and should be a factor in any decision to install a system. As will be shown, the potential part of the MON, (MON_P) provides insight into the need for the system even where the actual accident experience is missing, or low. It also provides an indication of the need for a RVG system on facilities not yet in operation or those in the planning or construction phase. The following paragraphs provided a detailed description of the two MON components.

(1) MON_A

The first component, MON_A, which depends upon the accident history of the RV roadway segment, is a measure of the RV hazard from the actual accident experience point of view. The accident history data is reflected by the three categorization indices, C_{1N}, C_{2N}, and C_{3N}, which incorporate RV fatalities, RV multiple vehicle accidents and total RV accidents, respectively, into the measurement of the RV hazard. Each index is composed of two parts which are summed. These two parts are computed from the accident frequency per mile and accident rate. This is done because reliance solely on accident frequency (or on accident rate) as a measure can be misleading when dealing with wide ranges of traffic volumes. For example, a location with a relatively high number of accidents per mile may appear to be quite hazardous. But if the traffic volume is exceptionally high at the location, the accident rate may not be abnormal and the situation may not be as bad as it appears. On the other hand, a location with relatively few accidents may show a very high accident rate because of low traffic volumes. Again, the situation may not be as abnormal as it appears. Use of the sum of rate and frequency tends to reduce the possibility of misleading results.

The process for calculating indices C_{1N}, C_{2N}, C_{3N}, whose data sources are annual RV fatalities, annual RV multiple vehicle accidents, and total annual RV accidents, respectively, is described in the User Guidelines (Reference 1).

(2) MON_P

The second component (MON_P) of the MON equation, is also composed of three categorization indices and is defined by the following equation:

$$MON_P = K_4C_{4N} + K_5C_{5N} + K_6C_{6N}$$

It is computed from roadway volumes, RV frequency and roadway geometry. It is, therefore, a measure of the potential of the RV hazard.

Categorization index C_{4N} is referred to as the exposure index. Two independent data sources are needed for its computation; roadway volumes and the frequency of RV occurrence. The average AADT on the RV problem section during the accident history time period is the first data item. The second data input is

the frequency of the RV hazard, which is expressed in terms of the average number of reduced visibility days per year within the study section. An RV day is defined as any day on which visibility at some point in the section is less than 0.25 mile (.40 Km).

This index is a measure of exposure of accidents related to reduced visibility, i.e., it assumes that the probability of accident occurrence is greatest when traffic volume is high and visibility is poor. In a high volume condition, the potential for vehicle conflict is heightened whereas when volumes are low there are characteristically wide gaps between vehicles, in which case the potential for conflict is significantly less. In terms of RV days, it is obvious that the more frequent the exposure to a RV environment, the higher the potential for conflict.

The fifth categorization index, C_{5N}, is a function of the number of entrance and exit ramps. The index is calculated by dividing the number of ramps by the length of the RV section. This index is provided because traffic flow in the immediate vicinity of an interchange is often subjected to speed reductions and weaving movements, and in a high volume condition, the potential for vehicle conflict increases. In a reduced visibility condition a hazardous situation is created in which the accident potential is increased even further.

The last categorization index, C_{6N}, is derived from the geometric characteristics of the RV problem area. The index is the sum of two parts. The first part is a function of roadway grade and the other part depends on the vertical and horizontal roadway alignment. Both of these geometric characteristics influence the traffic flow during ideal conditions. The effect of reduced visibility is to amplify their influence on the traffic flow. For example, on steep grades, slower moving vehicles such as trucks disrupt traffic flow by creating a bimodal speed distribution. In a reduced visibility condition, faster moving vehicles may not see the slower moving vehicle ahead and thus the potential for collision is increased. Vertical and horizontal roadway curvature can result in restrictive sight lines for the motorist. This impairment of visual range can be a contributing factor to an accident. The problem is amplified during RV conditions, since the motorist may temporarily lose sight of tail lights of preceding vehicles as they pass over the crest of the curve or around a sharp horizontal curve. This temporary loss of reference may create vehicle conflict.

Since precise data of this kind is difficult to obtain, a subjective ranking of the roadway grade and vertical and horizontal curvature is recommended. The ranking should be made by an individual familiar with the roadway geometrics. Both grade and horizontal and vertical alignment are assumed to make equal contributions to the geometric accident potential. The range of each of the two parts of this index is from 0 to 5, i.e., the user assigns a value from 0 to 5, which ranks the severity of roadway geometry. A value of 0 represents an ideal geometric condition, for example, a value of 0 for vertical and horizontal curvature might correspond to a tangent level section of an interstate roadway.

Any factor which amplifies the accident potential of either of the two index components should result in a higher component value than would be given

for the same location without this factor. Examples of such factors are: a large fraction of heavy truck traffic, or off-the-road emergency parking limited by natural features or by overpass structures.

The User Guidelines (loc cit) contain a step-by-step description of the calculating of C_{4N}, C_{5N} and C_{6N}.

(d) Weighting Factors (K Coefficients)

The coefficients, K_1, K_2, ...K_6 in the MON equation are used to weight the contribution of the categorization indices in proportion to their estimated importance. Selection of their magnitudes was achieved by averaging independent estimates of Task Force personnel. Two constraints were imposed on the selection process. The first constraint was that the importance of the MON_A and MON_P components of the MON equation be exactly the same (50-50 split). It was felt that the actual RV accident history experience and the potential for RV hazard should contribute equally to the MON.

The second constraint was that the sum of all six K coefficients should be 10. This in effect established a maximum value for the total MON. The selected weighting factors are presented in Table 4. Using the weighting factors in Table 4, the MON equation can be written as follows:

$$MON = 0.75C_{IN} + 0.90C_{2N} + 0.85C_{3N} + 2.6C_{4N} + 1.1C_{5N} + 1.3C_{6N}$$

The first three coefficients K_1, K_2 and K_3 are half of the values shown in Table 4 because of the fact that C_{1N}, C_{2N} and C_{3N} are actually the sum of two terms, one for accident rate and one for accident frequency.

TABLE 4. WEIGHTING FACTORS

Symbol	Categorization Index, C_{iN}	Weighting Factor Value
C_{1N}	RV Accident Fatalities	$K_1 = 1.5$
C_{2N}	RV Multiple Vehicle Accidents	$K_2 = 1.8$
C_{3N}	Total RV Accidents	$K_3 = 1.7$
C_{4N}	AADT'S and Number of RV Days	$K_4 = 2.6$
C_{5N}	Number of Entrance and Exit Ramps	$K_5 = 1.1$
C_{6N}	Roadway Grade, and Horizontal & Vertical Curvature	$K_6 = 1.3$
		SUM = 10.0

6. Utility Methodology

Several evaluation methods were available to make an economic comparison between the RVG systems considered. These methods were:

- Benefit/Cost
- Effectiveness/Cost
- Utility/Cost

The Benefit/Cost method is one of the most common evaluation techniques, and ideally represents the most meaningful measure of comparison. This is because a direct relationship can be obtained between the dollar value of the benefits attained and their respective cost. One shortcoming of this method, however, is that it is very difficult, if at all possible, to assign a dollar value to many of the benefits a system can provide. Thus, the benefit calculation is not complete, in the sense that system attributes to which dollar benefits can easily be attached are included, but those which do not have such tangible benefits (such as reliability or satisfaction of public demand), are not included. In this sense, the Benefit/Cost method is deficient in its ability to make valid comparisons.

The Effectiveness/Cost method is another common technique. It suffers from the same drawbacks as Benefit/Cost, in that the scaling of the various attributes for system effectiveness are subject to the same constraints as the benefit measures. Thus, the same conclusion applies, i.e., the usefulness is limited.

The Utility/Cost method is an alternate approach which allows a means for assessing all of the benefits of a candidate system, regardless of whether or not they are dollar-quantifiable. This method is more subjective than the others and relies heavily on sound judgement. It nevertheless represents a comprehensive examination of the problem and affords the opportunity for the inclusion of many important factors which are often ignored.

(a) System Utility Model

The Utility/Cost approach begins with the selection and weighting of a utility model. The model consists of a number of primary system objectives, each of which is accompanied by a group of "utility measures". The utility measures are descriptive of the extent to which a given system meets the objectives under which they are listed. Table 5 lists these objectives and utility measures for an RV system.

The objectives and the utility measures are then ranked and weighted. The method chosen for this procedure was open discussion during a Task Force meeting. A list of candidate objectives and measures was prepared, revised, added to and finally agreed upon by the Task Force, and the ranking and weighting of this list was conducted during the Second Task Force meeting in Cheyenne, Wyoming.

The results of the weighting are expressed in terms of "system values" in Table 5. These numbers are the product of the numerical weights of the utility

TABLE 5. UTILITY MODEL RANKING AND WEIGHTING

	Objectives and Measures	Rank	Weight	System Value
I	ROADWAY OPERATION (32%)			
	1. Reduce Accidents	1	60	19.2
	2. Maintain High Service Level	2	40	12.8
	TOTAL		100%	
II	SATISFY PUBLIC DEMAND (18%)			
	1. Provide Credible Advance Warning	1	70	12.6
	2. Reduce Driver Stress	2	20	3.6
	3. Public Reaction	3	10	1.8
	TOTAL		100%	
III	RELIABILITY AND MAINTAINABILITY (15%)			
	1. Reliability	1	50	7.5
	2. Preventive Maintenance Requirements	2	25	3.7
	3. Field Maintenance	3	15	2.3
	4. Central Maintenance	4	10	1.5
	TOTAL		100%	
IV	SYSTEM OPERATION (13%)			
	1. Manual Override	1	30	3.9
	2. Operating Complexity	2	30	3.9
	3. Central Control Capability	3	25	3.3
	4. Back-up Capability	4	15	1.9
	TOTAL		100%	
V	MONITORING CAPABILITY (9%)			
	1. Traffic Operations	1	50	4.5
	2. System Functions	2	50	4.5
	TOTAL		100%	

Table 5. Utility Model Ranking and Weighting (Continued)

	Objectives and Measures	Rank	Weight	System Value
VI	FLEXIBILITY (6%)			
	1. Ease of Modification	1	60	3.6
	2. Ease of Expansion	2	40	2.4
	TOTAL		100%	
VII	SECONDARY USES (4%)			
	1. Data Processing	1	50	2
	2. Non-RV Message Information	2	50	2
	TOTAL		100%	
VIII	INSTALLATION DISRUPTION (3%)			
	1. Service Disruption	1	50	1.5
	2. Installation Complexity	2	27	0.8
	3. Schedule Feasibility	3	23	0.7
	TOTAL		100%	

measures and the weights of the objectives under which they are listed. The list of utility measures and their corresponding system values constitutes the utility model for the RVG study.

(b) Compliance Factor

To arrive at a system utility, a "compliance factor" ranging in value from zero to ten is estimated for each utility measure, on the basis of the known characteristics of the system. The sum of the products of system values and compliance factors is the system utility. The model has been constructed so that values for the system utility can range from 0 to 1000.

7. System Cost Methodology

System costs in this report are expressed in terms of the present worth of the system as of January 1, 1977. The present worth includes the capital cost plus the maintenance and operational costs, all adjusted for inflation. To arrive at the total present worth, the following procedure was used:

- Determine the original cost of the system and the mean date of installation

- Using the National Consumer Price Index (CPI) values, determine inflation factors from which to compute the inflated cost of the system on January 1, 1977

- Similarly, determine the inflated maintenance and operational cost in January 1, 1977

- Using an average compounded inflation rate of 6.5% (based on CPI table) and a 10% rate as the cost of borrowing money, determine the present worth of maintenance and operational cost from 1/1/77 to 1/1/92 (15 years)

- For system components that have a shorter life than 15 years, new components are assumed to be purchased, at an inflated cost, at the required intervals

- The capital cost as of 1/1/77 is added to the present worth of the maintenance and operational cost of 1/1/77 to give the total present worth.

Table 6 lists all the necessary formulae used to compute these cost quantities.

b. SAMPLE SYSTEMS SELECTED FOR EVALUATION

The sample system which were selected for economic analysis were previously listed in Table 2. In addition to this basic set of existing systems, several variations on each system were subjected to the same analysis. The variations represent additions or deletions of certain capabilities, and thus provide a means of judging the value of these capabilities. The entire list of existing systems and variations which was analyzed is shown in Table 7, with the existing system in each indicated by an asterisk.

c. RESULTS OF THE ECONOMIC ANALYSIS

Table 8 provides a complete summary of the cost analysis for each of the sample systems and their variations. The original capitalization costs are shown, as well as capitalization costs at the base date of January 1, 1977. The total present worth which is shown is the sum of the capitalization cost (1-1-77) plus the present worth of the yearly maintenance and operation costs.

Tables 9 through 14 provide the results of the utility analysis for the sample systems. Compliance values are listed for each of the utility measures. Total utility is computed for each system by summing the product of the compliance and the system value of each utility measure.

Appendix D provides a description of the considerations used in assigning compliance values. It also provides tables of backup data for each system. These data, which are obtained from interviews, etc., were used in arriving at the compliance values. Figures 3 through 8 show the results of the utility-cost comparisons for each sample system and its variations.

TABLE 6. PRESENT WORTH AND INFLATION FORMULAE

1. Determination of the Capital Cost of System on 1-1-77; Taking into Account Inflation:

$$CA_I = (OC_m) \times (IF_m)$$

where:

CA_I = Inflated Capital Cost of System on 1-1-77

OC_m = Original Cost of System in Year m

IF_m = Inflation Factor for Year m obtained from the table below:

Year (m)	Inflation Factor* (IF_m)	Year (m)	Inflation Factor* (IF_m)
67	1.818	72	1.451
68	1.745	73	1.366
69	1.656	74	1.231
70	1.563	75	1.128
71	1.499	77	1.000

2. Present Worth of Future Maintenance and Operation Costs

Assume n equal payments for maintenance and operation of P subject to an inflationary rate of r per year. Also, assume that the inflation rate is compounded in the nth year the nominal payment P costs $(1 + r)^n P$. The interest rate is i per year.

Year	Payment	Present Value
1	$(1 + r)\ P$	$\frac{(1 + r)\ P}{1 + i}$
.		
.		
.		
n	$(1 + r)^n P$	$\frac{(1 + r)^n P}{(1 + i)^n}$

Table 6. Present Worth and Inflation Formulae (Continued)

Present Worth of Future Maintenance and Operation Costs Over n Years

$$PV_n = P\,(f + f^2 + \cdots + f^n)$$

where $f = \frac{(1 + r)}{1 + i}$

or

$$PV_n = Pf\,\frac{(1 - f^n)}{1 - f}$$

3. Total Present Worth of System

$$PV_T = CA_I + PV_n$$

where:

PV_T = Total Present Worth of System

CA_I = Inflated Capital Cost of System on 1-1-77

PV_n = Present Worth of Future Maintenance and Operation Costs Over n Years

TABLE 7. SAMPLE SYSTEMS FOR ECONOMIC ANALYSIS

System	System Description
ARIZONA	I-8 & I-10: 82 MILES (131.9Km) BETWEEN PHOENIX & TUSCON
A1	Broadcast system only with 20 fixed signs
A2	40 variable message signs (3 messages each), individually controlled
A3*	40 variable message signs (2 messages each), with commercial broadcast system
A4	20 variable message signs (2 messages each), with commercial broadcast system
CALIFORNIA	ROUTE 91: 20 MILES (32.2Km) BETWEEN CORONA & RIVERSIDE
C1*	Delineation system with raised pavement markers
C2	Variable message sign trucks (VELCRO)
C3	Variable message sign trucks (bulb matrix)

Table 7. Sample Systems For Economic Analysis (Continued)

System	System Description
NEW JERSEY	NJ TURNPIKE 46.4 MILES (74.7Km) BETWEEN INTERCHANGE 9 & INTERCHANGE 18 (INCLUDING BOTH EAST AND WEST ALIGNMENTS)
N1*	Variable message signs
N2	System N1 with five fog detectors
OREGON	I-5 6.4: MILES (10.3Km) NEAR ALBANY
O1	Delineation system with raised reflective markers
O2	8 folding type signs with flashers
O3*	6 variable message signs with remote control
O4	System 03 with fog detectors
VIRGINIA	I-64: AFTON MTN 5.8 MILES (9.3Km) NEAR STAUNTON
V1	Delineation System with raised reflective markers
V2*	Pavement inset lights, 2 advanced warning signs plus 1VMS
V3*	System V2 with 15 additional VMS
V4	Advanced V2 system with fog detectors & computer control
V5	System V4 with 2 SLSW signs outside hazard area
WYOMING	I-80: 60 MILES (96.6Km) BETWEEN LARAMIE & WALCOTT JUNCTION
W1	Highway advisory radio
W2	150,000 linear ft of snow fencing
W3	2 computer controlled variable message signs
W4*	Combination of W1, W2, & W3

*indicates existing system

d. SAMPLE SYSTEM EVALUATION SUMMARIES

The evaluation summaries for each sample system are contained in Appendix E. Each summary consists of a docket that includes a case history of the system, tracing its evaluation and providing answers to questions such as system objectives, effectiveness, performance and economic justifiability. It also contains the results of the cost-utility and measure-of-need computations.

TABLE 8. SUMMARY OF SYSTEM COST ANALYSIS

Yr	Sys**	Orig. Maint. Orig. Cost ($)	Orig. Maint. & Oper. ($)	Orig. Maint. Cost @ 1/1/77, ($)	Maint. & Oper. ($ per year)	Pst. Worth of Maint. & Oper.(1), ($)	Total Present Worth ($)
'73	A1	(Estimated)		2,000	2,500	29,000	31,000
	A2	737,733	33,111	1,008,000	45,230	529,000	1,537,000
	A3	(Estimated)		1,010,000	47,730	558,000	1,568,000
	A4	(Estimated)		504,000	25,310	296,000	800,000
'75	C1	34,400	6,060	39,000	6,840	80,000	119,000
	C2			12,000	(Replaced every 8 yrs.)(2)	11,300	23,300
	C3			18,100	(Replaced every 8 yrs.)(3)	13,600	31,700
	N1	520,000		687,000	12,400	145,000	832,000
	N2			722,000	13,200	154,000	876,000
	01	(Estimated)		10,800	(Replaced every 1.5 yrs.)		84,300
'68	02	2,000		3,500	12	150	3,650
'68	03	151,000		263,500	2,060	24,100	287,600
'68	04			295,800	3,200	37,400	333,200
'75	V1	27,000		32,000	1,970	23,000	55,000
'75	V2	1,845,000		2,081,000	18,930	221,000	2,302,000
'75	V3	2,121,000		2,393,000	28,580	334,000	2,727,000
	V4			2,447,000	14,960	175,000	2,622,000
	V5			2,567,000	14,960	175,000	2,742,000
'75	W1	150,000	11,300	169,000	12,700	149,000	80,000*
	W2	1,552,000		2,135,000			2,135,000
'75	W3	250,000	6,700	282,000	7,500	88,000	93,000
'75	W4	1,992,000	23,750	2,639,000	20,600	313,000	2,300,000*

*Includes only 25% of VMS & HAR cost
**See Table 7 for symbol meaning
(1)Based on: 6.5% compounded inflation rate and 10.0% interest rate
(2)Cost = $1,624
(3)Cost = $1,966

TABLE 9. ARIZONA - UTILITY RATINGS

Utility Measure	Sys Val	A1 Comp	A1 Util	A2 Comp	A2 Util	A3 Comp	A3 Util	A4 Comp	A4 Util
I. ROADWAY OPERATION									
1. Reduce Accidents	19.2	1	19.2	2.5	48.0	2.5	48.0	2.5	48.0
2. Maintain H/S Level	12.8	1	12.8	2.7	34.6	2.7	34.6	2.6	33.3
II. SATISFY PUBLIC DEMAND									
1. Provide Credible A/W	12.6	5	63.0	5.0	63.0	6.5	81.9	6.0	75.6
2. Reduce Driver Stress	3.6	2	7.2	5.5	19.8	5.5	19.8	5.5	19.8
3. Public Reaction	1.8	3	5.4	6.0	10.8	7.5	13.5	7.0	12.6
III. RELIABILITY & MAINTAINABILITY									
1. Reliability	7.5	7	52.5	5.0	37.5	6.0	45.0	6.5	48.7
2. Preventive Maint. Reqts	3.7	7	25.9	4.0	14.8	5.0	18.5	5.5	20.4
3. Field Maint.	2.3	9	20.7	3.0	6.9	4.0	9.2	4.5	10.3
4. Central Maint.	1.5	7	10.5	5.5	8.3	5.5	8.3	6.0	9.0
IV. SYSTEM OPERATION									
1. Manual Override	3.9	0	0	0	0	0	0	0	0
2. Operating Complexity	3.9	8	31.2	5.0	19.5	8.5	33.2	8.5	33.2
3. Central Control Capab.	3.3	7	23.1	7.0	23.1	7.0	23.1	7.0	23.1
4. Backup Capability	1.9	5	9.5	4.0	7.6	5.0	9.5	5.0	9.5
V. MONITORING CAPABILITY									
1. Traffic Operation	4.5	0	0	0	0	0	0	0	0
2. System Function	4.5	0	0	4.0	18.0	4.0	18.0	4.0	18.0
VI. FLEXIBILITY									
1. Ease of Modification	3.6	5	18.0	5.0	18.0	4.5	16.2	5.0	18.0
2. Ease of Expansion	2.4	6	14.4	3.0	7.2	3.0	7.2	3.0	7.2
VII. SECONDARY USES									
1. Data Processing	2.0	0	0	0	0	0	0	0	0
2. Non-RV Mess. Info.	2.0	6	12.0	5.0	10.0	6.0	12.0	6.0	12.0
VIII. INSTALLATION DISRUPTION									
1. Service Disruption	1.5	10	15.0	6.0	9.0	7.0	10.5	7.25	10.9
2. Installation Complexity	0.8	9.5	7.6	7.0	5.6	6.5	5.2	7.0	5.6
3. Schedule Feasibility	0.7	9.5	6.7	8.0	5.6	8.0	5.6	8.25	5.8
	100.0		354.7		367.2		419.16		420.9

TABLE 10. CALIFORNIA - UTILITY RATINGS

Utility Measure	Sys Val	C1		C2		C3	
		Comp	Util	Comp	Util	Comp	Util
I. ROADWAY OPERATION							
1. Reduce Accidents	19.2	3	57.6	3.5	67.2	3.5	67.2
2. Maintain H/S Level	12.8	4	51.2	4.5	57.6	5.0	64.0
II. SATISFY PUBLIC DEMAND							
1. Provide Credible A/W	12.6	1	12.6	5.0	63.0	5.0	63.0
2. Reduce Driver Stress	3.6	3.5	12.6	3.5	12.6	4.0	14.4
Public Reaction	1.8	4.0	7.2	2.5	4.5	3.0	5.4
III. RELIABILITY & MAINTAINABILITY							
1. Reliability	7.5	9	67.5	9.0	67.5	8.0	60.0
2. Preventive Maint. Reqts	3.7	9	33.3	9.0	33.3	8.0	29.6
3. Field Maint.	2.3	8	18.4	9.0	20.7	7.0	16.1
4. Central Maint.	1.5	10	15.0	9.0	13.5	9.0	13.5
IV. SYSTEM OPERATION							
1. Manual Override	3.9	0	0	0	0	0	0
2. Operating Complexity	3.9	10	39.0	9.5	37.1	9.0	35.1
3. Central Control Capab.	3.3	0	0	0	0	0	0
4. Backup Capability	1.9	0	0	1.5	2.8	10.0	19.0
V. MONITORING CAPABILITY							
1. Traffic Operation	4.5	0	0	4.0	18.0	4.0	18.0
2. System Function	4.5	0	0	9.0	40.5	9.0	40.5
VI. FLEXIBILITY							
1. Ease of Modification	3.6	1	3.6	6.0	21.6	5.0	18.0
2. Ease of Expansion	2.4	4	9.6	6.0	14.4	6.0	14.4
VII. SECONDARY USES							
1. Data Processing	2.0	0	0	0	0	0	0
2. Non-RV Mess. Info.	2.0	0	0	8.5	17.0	8.0	16.0
VIII. INSTALLATION DISRUPTION							
1. Service Disruption	1.5	6	9.0	9.0	13.5	9.0	13.5
2. Installation Complexity	0.8	8	6.4	9.0	7.2	9.0	7.2
3. Schedule Feasibility	0.7	9	6.3	8.0	5.6	7.5	5.3
	100.0		349.3		517.6		502.2

TABLE 11. NEW JERSEY TURNPIKE - UTILITY RATINGS

Utility Measure	Sys Val	N1 Comp	N1 Util	N2 Comp	N2 Util
I. ROADWAY OPERATION					
1. Reduce Accidents	19.2	6	115.2	7.0	134.4
2. Maintain H/S Level	12.8	6	76.8	7.0	89.6
II. SATISFY PUBLIC DEMAND					
1. Provide Credible A/W	12.6	6	75.6	7.0	88.2
2. Reduce Driver Stress	3.6	6	21.6	6.5	23.4
3. Public Reaction	1.8	6	10.8	7.0	12.6
III. RELIABILITY & MAINTAINABILITY					
1. Reliability	7.5	6.5	47.8	6.4	48.0
2. Preventive Maint. Reqts	3.7	6.5	24.0	6.4	23.7
3. Field Maint.	2.3	5.0	11.5	4.8	11.0
4. Central Maint.	1.5	6.5	9.8	6.0	9.0
IV. SYSTEM OPERATION					
1. Manual Override	3.9	8	31.2	8.0	31.2
2. Operating Complexity	3.9	7.5	29.2	7.5	29.3
3. Central Control Capab.	3.3	9.0	29.7	9.1	30.0
4. Backup Capability	1.9	8.0	15.2	8.0	17.1
V. MONITORING CAPABILITY					
1. Traffic Operation	4.5	8	36.0	8.0	36.0
2. System Function	4.5	7.5	33.8	7.5	33.8
VI. FLEXIBILITY					
1. Ease of Modification	3.6	3	10.8	3.0	10.8
2. Ease of Expansion	2.4	4	9.6	4.0	9.6
VII. SECONDARY USES					
1. Data Processing	2.0	7	14.0	6.8	13.6
2. Non-RV Mess. Info.	2.0	8	16.0	8.0	16.0
VIII. INSTALLATION DISRUPTION					
1. Service Disruption	1.5	5.5	8.2	5.5	8.2
2. Installation Complexity	0.8	5.5	4.4	5.5	4.4
3. Schedule Feasibility	0.7	5	3.5	5.0	3.5
	100.0		635.7		683.4

TABLE 12. OREGON - UTILITY RATINGS

Utility Measure	Sys Val	O1 Comp	O1 Util	O2 Comp	O2 Util	O3 Comp	O3 Util	O4 Comp	O4 Util
I. ROADWAY OPERATION									
1. Reduce Accidents	19.2	3	57.6	2.0	38.4	7.0	134.4	7.25	139.2
2. Maintain H/S Level	12.8	4	51.2	3.0	38.4	5.5	70.4	6.5	83.2
II. SATISFY PUBLIC DEMAND									
1. Provide Credible A/W	12.6	1	12.6	2.0	25.2	7.5	94.5	8.0	100.8
2. Reduce Driver Stress	3.6	3.5	12.6	2.5	9.0	5.5	19.8	5.5	19.8
3. Public Reaction	1.8	4	7.2	2.0	3.6	7.5	13.5	7.5	13.5
III. RELIABILITY & MAINTAINABILITY									
1. Reliability	7.5	9	67.5	9.5	71.3	8.0	60.0	7.75	58.1
2. Preventive Maint. Reqts	3.7	8	29.6	9.5	35.1	8.0	29.6	7.75	28.7
3. Field Maint.	2.3	5	11.5	9.0	20.7	8.0	18.4	7.75	17.8
4. Central Maint.	1.5	10	15.0	10.0	15.0	8.0	12.0	7.75	11.6
IV. SYSTEM OPERATION									
1. Manual Override	3.9	0	0	0	0	0	0	0	0
2. Operating Complexity	3.9	10	39.0	10.0	39.0	8.0	31.2	8.0	31.2
3. Central Control Capab.	3.3	0	0	0	0	8.0	26.4	8.25	27.2
4. Backup Capability	1.9	0	0	0	0	7.5	14.3	7.5	14.3
V. MONITORING CAPABILITY									
1. Traffic Operation	4.5	0	0	0	0	0	0	0	0
2. System Function	4.5	0	0	0	0	4.0	18.0	4.0	18.0
VI. FLEXIBILITY									
1. Ease of Modification	3.6	1	3.6	2.0	7.2	3.0	10.8	3.0	10.8
2. Ease of Expansion	2.4	4	9.6	7.0	16.8	3.0	7.2	3.0	7.2
VII. SECONDARY USES									
1. Data Processing	2.0	0	0	0	0	0	0	0	0
2. Non-RV Mess. Info.	2.0	0	0	0	0	5.5	11.0	5.5	11.0
VIII. INSTALLATION DISRUPTION									
1. Service Disruption	1.5	6	9.0	9.0	13.5	6.5	9.7	6.5	9.8
2. Installation Complexity	0.8	8	6.4	9.0	7.2	7.0	5.6	7.0	5.6
3. Schedule Feasibility	0.7	9	6.3	10.0	7.0	7.0	4.9	7.0	4.9
	100.0		338.7		347.4		591.7		612.7

TABLE 13. VIRGINIA - UTILITY RATINGS

Utility Measure	Sys Val	V1		V2		V3		V4		V5	
		Comp	Util	Comp	Util	Comp	Util	Comp	Util	Comp	Util
I. ROADWAY OPERATION											
1. Reduce Accidents	19.2	3	57.6	5.0	96.0	5.25	100.8	7.0	134.4	7.5	144.0
2. Maintain H/S Level	12.8	4	51.2	6.0	76.8	6.5	83.2	7.5	96.0	8.0	102.4
II. SATISFY PUBLIC DEMAND											
1. Provide Credible A/W	12.6	1	12.6	4.5	56.7	4.5	56.7	6.25	78.8	8.5	107.1
2. Reduce Driver Stress	3.6	3.5	12.6	5.0	18.0	5.25	18.9	7.0	25.2	7.5	27.0
3. Public Reaction	1.8	4	7.2	7.5	13.5	7.75	14.0	8.0	14.4	8.5	15.3
III. RELIABILITY & MAINTAINABILITY											
1. Reliability	7.5	9	67.5	6.8	51.0	6.3	47.2	7.5	56.3	7.0	52.5
2. Preventive Maint. Reqts	3.7	9	33.3	4.0	14.8	3.5	13.0	7.0	25.9	6.75	25.0
3. Field Maint.	2.3	8	10.4	4.0	9.2	3.5	8.0	7.0	16.1	6.75	15.5
4. Central Maint.	1.5	10	15.0	4.5	6.8	4.0	6.0	7.0	10.5	7.0	10.5
IV. SYSTEM OPERATION											
1. Manual Override	3.9	0	0	0	0	0	0	9.0	35.1	9.0	35.1
2. Operating Complexity	3.9	10	39	8.0	31.2	8.0	31.2	8.5	33.2	8.5	33.2
3. Central Control Capab.	3.3	0	0	5.0	16.5	5.0	16.5	8.0	26.4	8.0	26.4
4. Backup Capability	1.9	0	0	0	0	0	0	8.0	15.2	8.0	15.2
V. MONITORING CAPABILITY											
1. Traffic Operation	4.5	0	0	0	0	0	0	5.0	22.5	5.0	22.5
2. System Function	4.5	0	0	2.0	9	2.0	9	7.5	33.75	7.5	33.75
VI. FLEXIBILITY											
1. Ease of Modification	3.6	1	4.5	2.0	7.2	2.0	7.2	6.0	21.6	6.0	21.6
2. Ease of Expansion	2.4	4	18.0	3.0	7.2	3.0	7.2	4.0	9.6	4.0	9.6
VII. SECONDARY USES											
1. Data Processing	2.0	0	0	0	0	0	0	5.0	10.0	5.0	10.0
2. Non-RV Mess. Info.	2.0	0	0	0	0	0	0	0	0	0	0
VIII. INSTALLATION DISRUPTION											
1. Service Disruption	1.5	6	9	7.0	10.5	7.0	9	7.0	10.5	7.0	10.5
2. Installation Complexity	0.8	8	6.4	6.0	4.8	6.0	4.8	6.5	5.2	6.5	5.2
3. Schedule Feasibility	0.7	9	6.3	6.5	4.5	8.0	5.6	8.0	5.6	7.75	5.4
	100.0		358.6		433.0		438.3		686.3		727.8

TABLE 14. WYOMING - UTILITY RATINGS

Utility Measure	Sys Val	W1		W2		W3		W4	
		Comp	Util	Comp	Util	Comp	Util	Comp	Util
I. ROADWAY OPERATION									
1. Reduce Accidents	19.2	1.5	28.8	4.0	76.8	5.0	96.0	6.0	115.2
2. Maintain H/S Level	12.8	1	12.8	5.5	70.4	5.0	64.0	5.5	70.4
II. SATISFY PUBLIC DEMAND									
1. Provide Credible A/W	12.6	5.5	69.3	0	0	6.0	75.6	6.0	75.6
2. Reduce Driver Stress	3.6	1.5	5.4	4.0	14.4	4.0	14.4	5.0	18.0
3. Public Reaction	1.8	3	5.4	5.5	9.9	7.5	13.5	7.5	13.5
III. RELIABILITY & MAINTAINABILITY									
1. Reliability	7.5	4	30.0	9.0	67.5	7.5	56.3	7.25	54.4
2. Preventive Maint. Reqts	3.7	4.5	16.7	9.0	33.3	6.0	22.2	5.75	21.3
3. Field Maint.	2.3	4.5	10.3	9.0	20.7	6.0	13.8	5.0	11.5
4. Central Maint.	1.5	7	10.5	10.0	15.0	7.0	10.5	7.0	10.5
IV. SYSTEM OPERATION									
1. Manual Override	3.9	0	0	0	0	0	0	0	0
2. Operating Complexity	3.9	8	31.2	10.0	39.0	8.0	31.2	7.0	27.3
3. Central Control Capab.	3.3	3	9.9	0	0	7.5	24.7	7.5	24.7
4. Backup Capability	1.9	5	9.5	0	0	0	0	2.0	3.8
V. MONITORING CAPABILITY									
1. Traffic Operation	4.5	0	0	0	0	0	0	0	0
2. System Function	4.5	0	0	0	0	6.5	29.3	6.5	29.3
VI. FLEXIBILITY									
1. Ease of Modification	3.6	3	10.8	1.0	3.6	5.0	18.0	5.0	18.0
2. Ease of Expansion	2.4	4	9.6	3.5	8.4	6.0	14.4	6.0	14.4
VII. SECONDARY USES									
1. Data Processing	2.0	0	0	0	0	3.0	6.0	3.0	6.0
2. Non-RV Mess. Info.	2.0	6	12	0	0	7.0	14.0	7.5	15.0
VIII. INSTALLATION DISRUPTION									
1. Service Disruption	1.5	8.5	12.8	10.0	15.0	6.0	9.0	5.75	8.6
2. Installation Complexity	0.8	7	5.6	7.0	5.6	6.0	4.8	5.75	4.6
3. Schedule Feasibility	0.7	7	4.9	7.0	4.9	7.0	4.2	6.0	4.2
	100.0		295.5		384.5		521.9		546.3

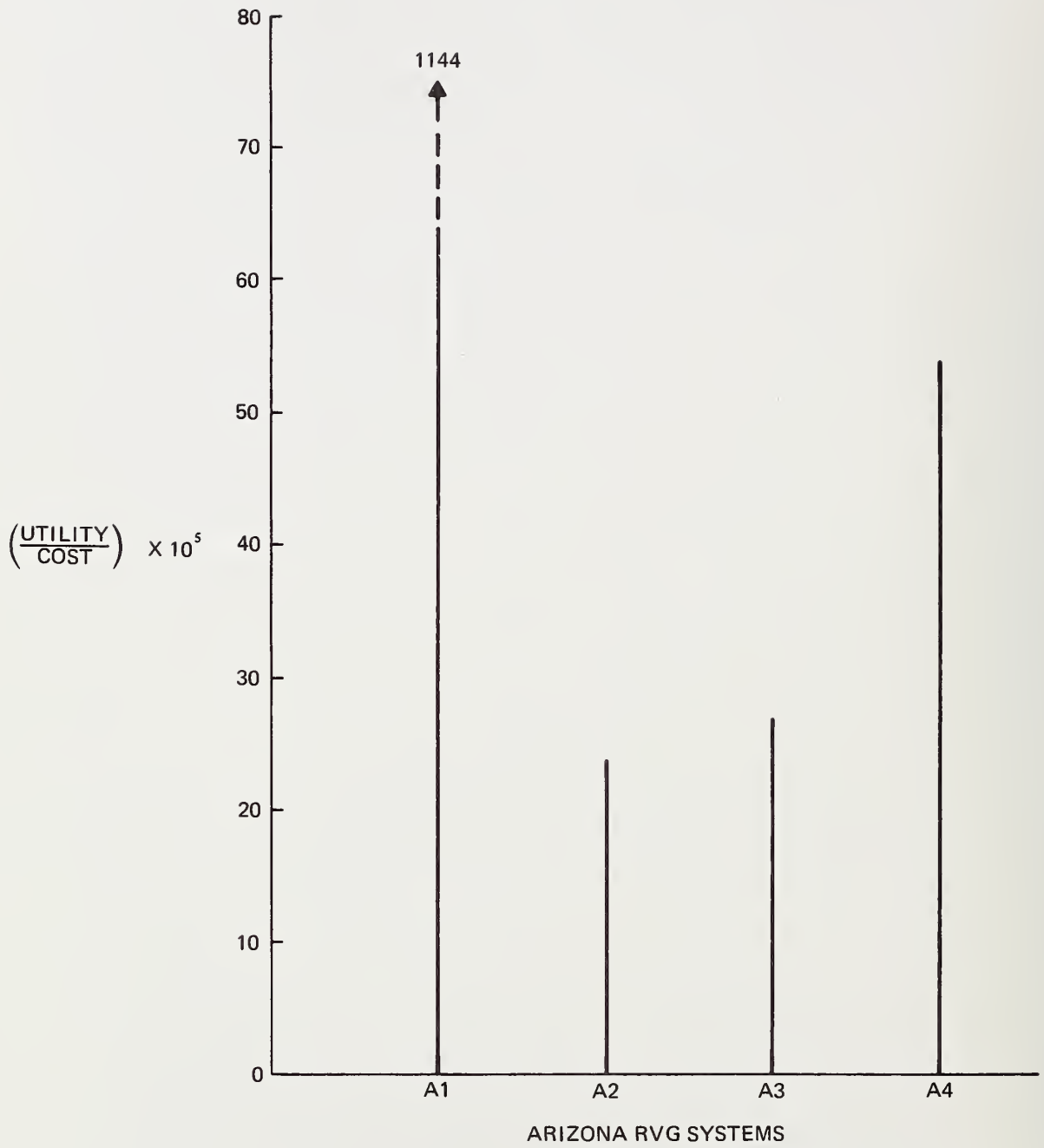


Figure 3. Utility Cost Ratios - Arizona

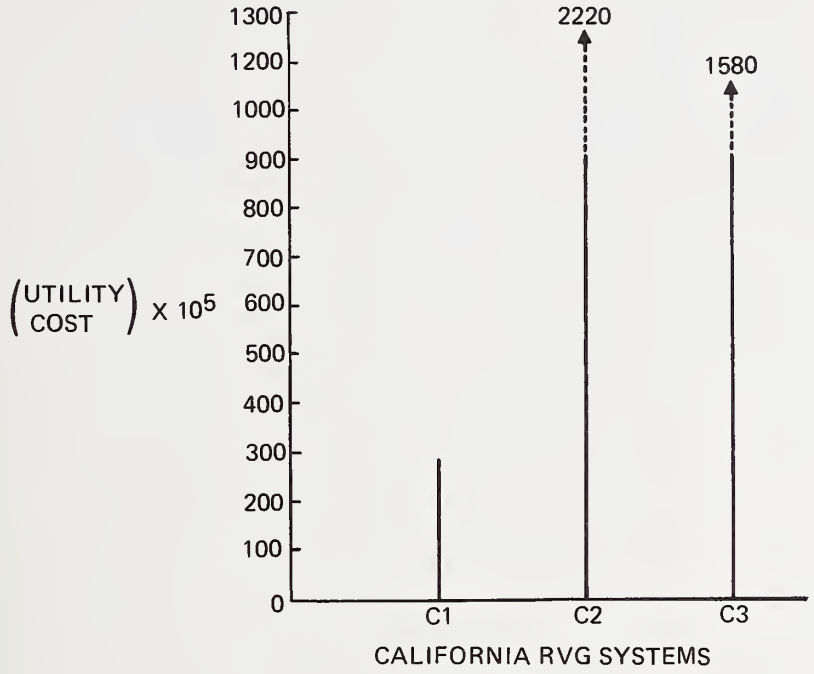


Figure 4. Utility/Cost Ratios - California

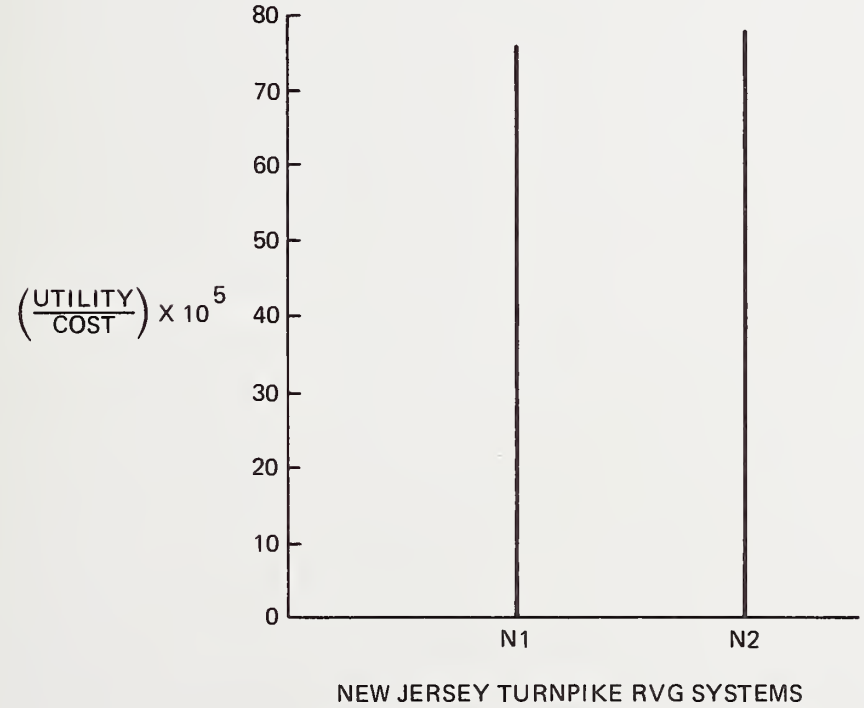


Figure 5. Utility/Cost Ratios - New Jersey Turnpike

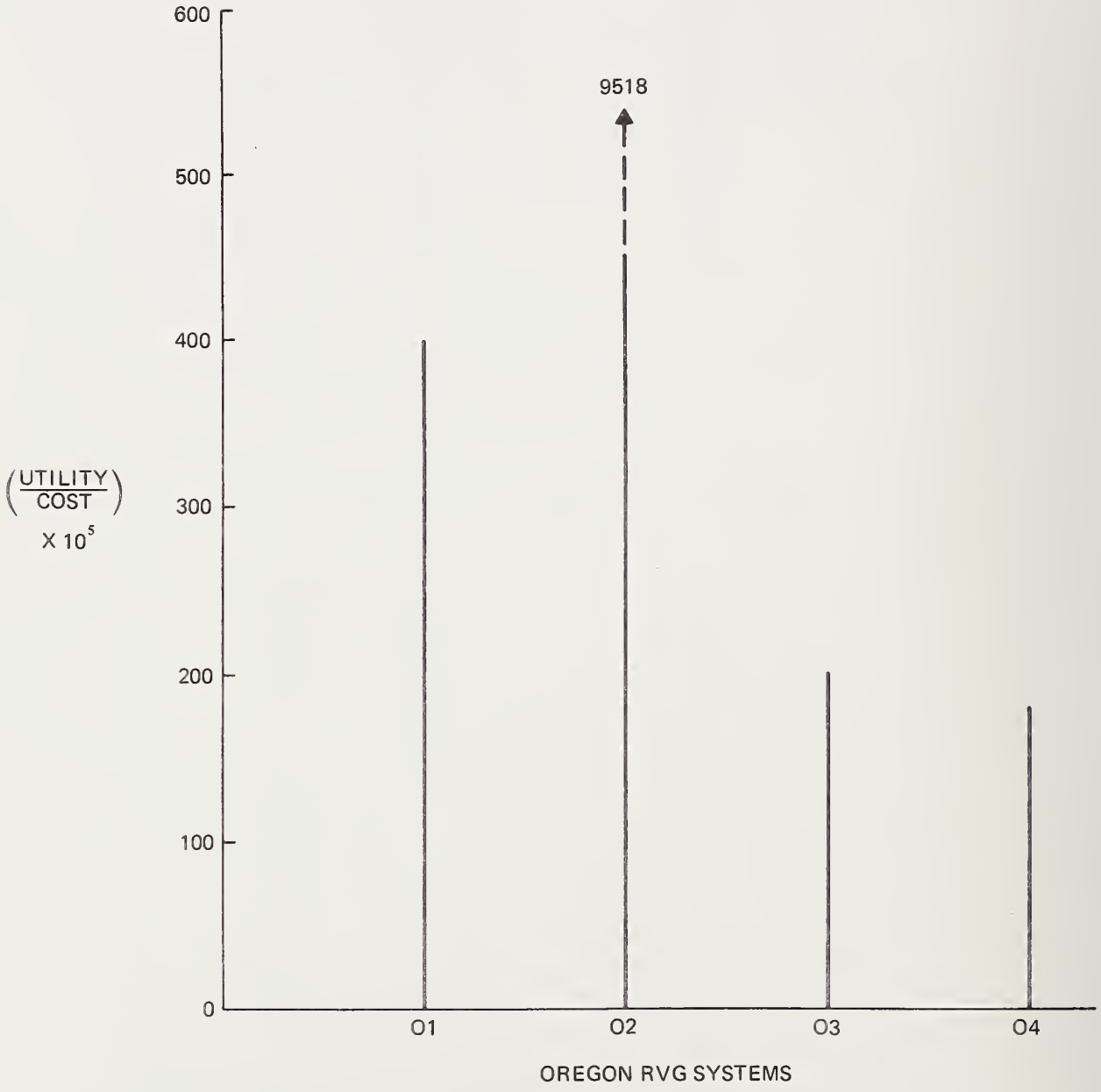


Figure 6. Utility/Cost Ratios - Oregon

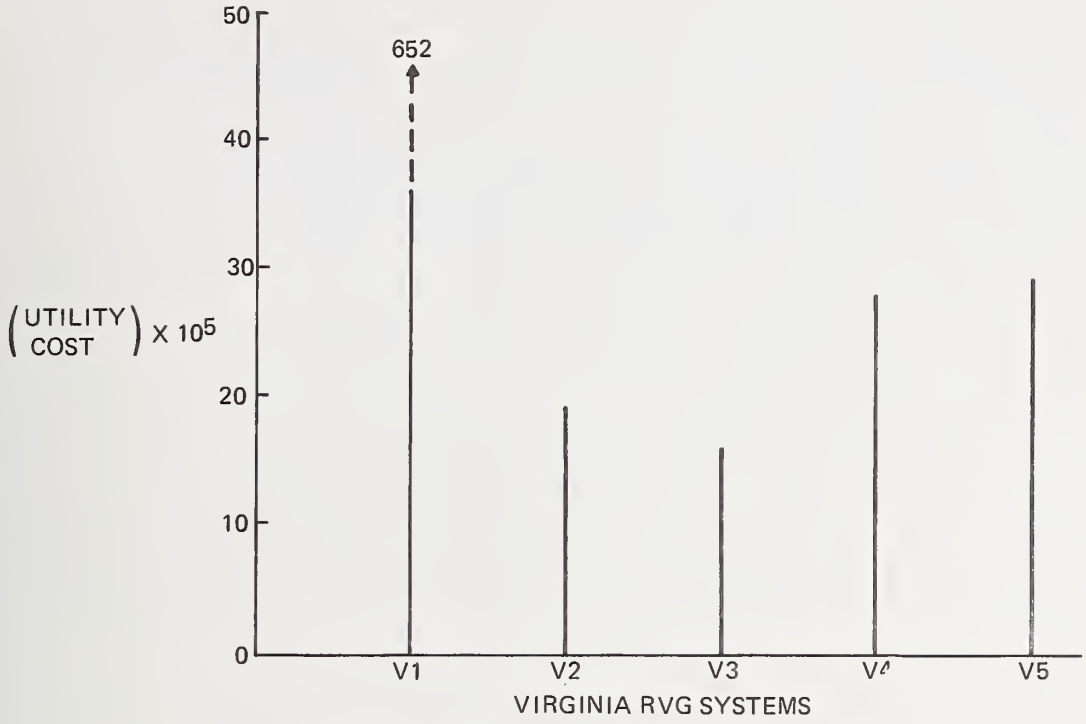


Figure 7. Utility/Cost Ratios - Virginia

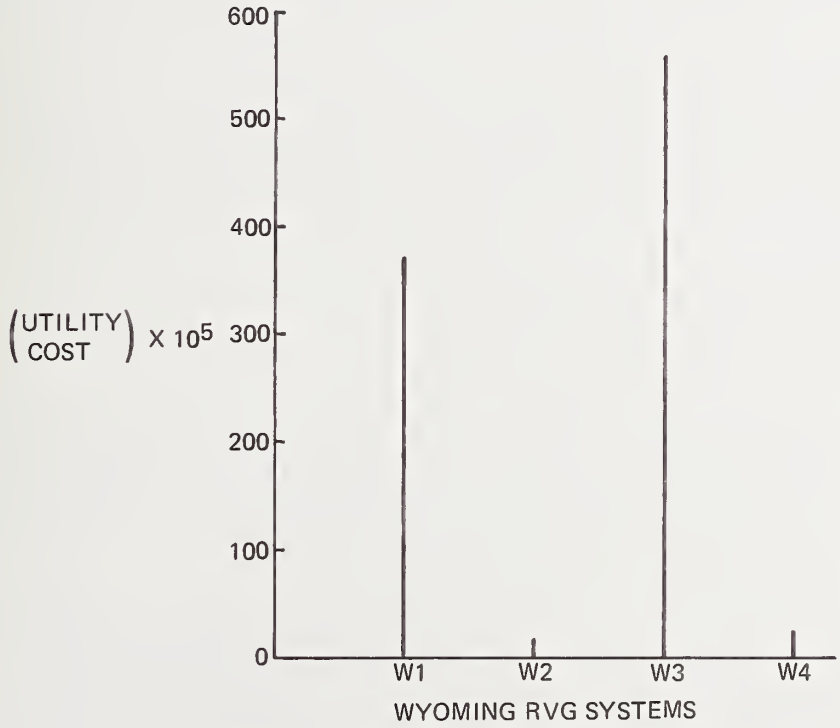


Figure 8. Utility/Cost Ratios - Wyoming

3-4 TASK G: SYSTEMS DEFINITION

This section provides scenarios, design details, cost and utility estimates for a spectrum of nine reduced visibility systems and represents the findings of Task G.

The objective of this task is to provide cost and utility data, with measure of need as a parameter, which will enable rough estimates of system costs to be made for a location with a known length and a known measure of need.

The nine systems fall into three length categories:

- Point - problem area one mile (1.61 Km) or less in length
- Medium - problem area 10 to 30 miles (16.1 to 48.3 Km) long
- Long - problem area more than 30 miles (48.3 Km) long

For each length, three systems are defined by three different sets of problem area characteristics. (See Appendix F.) Each set of characteristics corresponds to a specific reduced visibility MON range. The three measure of need (MON) categories are:

- Low - $10 \leq$ MON < 25
- Medium - $25 \leq$ MON < 40
- High - MON ≥ 40

a. SYSTEMS DESIGN

In the following paragraphs, the nine problem area scenarios (paragraph 3-4a.1.) are described. The problem characteristics (paragraph 3-4a.2.) of each scenario are extracted, and the problem characteristics are related to the system elements (paragraph 3-4a.3.).

1. Problem Area Scenarios

(a) Point Location High MON

The problem location is a bridge about a mile (1.61 Km) long over a marshy area near the coast. (See Figure 9.) The roadway is a four lane interstate, and the area is subjected to dense fog rising from the marshes, on the average of forty days a year. Visibility can frequently drop below 300 feet (91.5M). Almost invariably, the problem occurs during pre-dawn hours.

In addition to the fog problem, icing of the bridge can occur either simultaneously or as a separate condition. High winds are also a problem because of the proximity to the ocean and the unimpeded reach of the marshes.

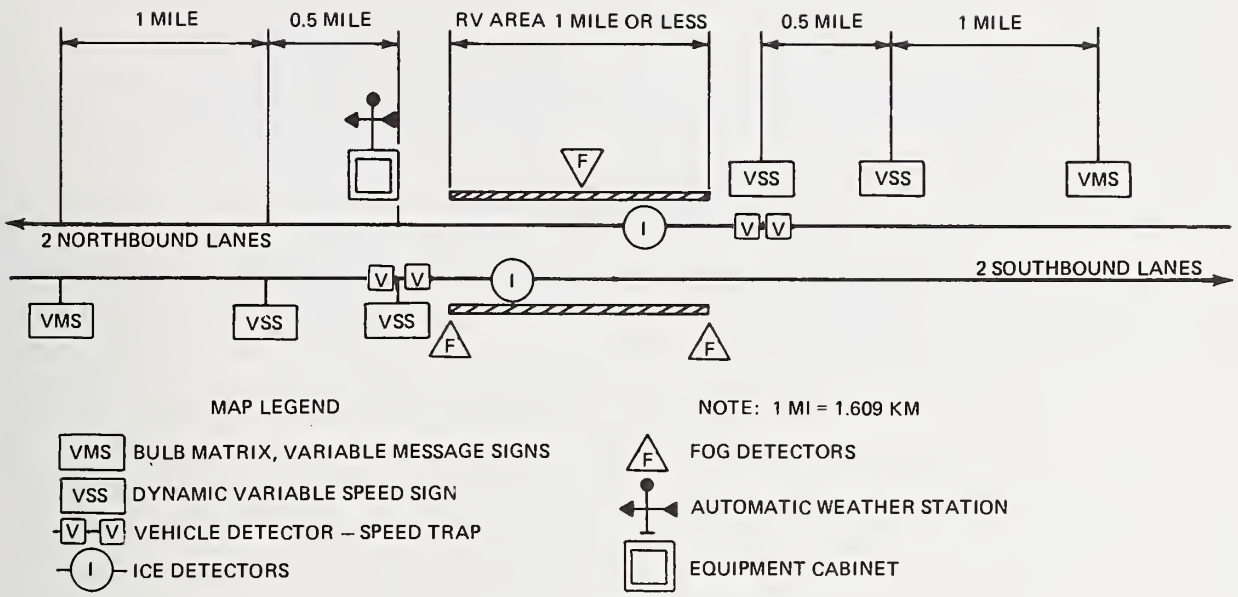


Figure 9. Point System - Problem Area

This stretch of roadway is remote and infrequently patrolled, but the AADT is 18,000 vehicles per day. No other roads exist through the marshy area, so that diversion of traffic is not a possibility.

The accident history of the roadway has been fairly good, from a reduced visibility point of view, until two recent chain reaction collisions in early morning fog. Reduced visibility aids to motorists are minimal in the area - striping is standard for interstate highways, and no special delineators have been installed to date.

Congestion resulting from heavy traffic is rare, except in the case of isolated incidents. Because of the remoteness of the area there are no special events which require traffic control treatment, which could affect the decision as to what kind of reduced visibility system is required.

Following the chain reaction collision, traffic operations personnel conducted speed studies, and discovered a significant increase in the spread of vehicle speeds during fog, leading to the conclusion that a bimodal speed distribution was at least partly responsible for the collisions.

(b) Point Location - Medium MON

The physical configuration of this problem area is the same as for the high MON location, but the AADT is lower - 11,000 per day, - and the fog problem, while occurring as frequently, is not as intense. Very often the visibility is limited to 300 - 1,000 feet (91.5 - 305 meters), but rarely is it less than 300 ft. (91.5 meters).

There have never been any chain reaction fog collisions on the bridge, but there have been several in which two or more vehicles were involved.

The area is not subject to very low temperature, and does not have bridge icing or suffer from hazards due to strong winds.

(c) Point Location - Low MON

The physical configuration of this problem area is the same as for the medium MON location, but the AADT is in the range of 6000-8000 vehicles per day. The fog problem is characterized by visibilities rarely less than 1000 ft. (305 meters) during fog episodes.

(d) Medium Length Location - High MON

The problem area is a four lane (two in each direction) interstate in a remote area. (See Figure 10.) The AADT is approximately 11,000 vehicles per day. There are four major interchanges in the problem area, which is twenty miles (32.2 Km) in length, but no parallel roads or alternates exist through the area.

Fog occurs frequently during the fall and spring, and is fairly uniform over the entire area. Historical data have revealed ten locations which permit visibility conditions within four sections to be predicted accurately. Fog density is such that the visibility is often less than 300 ft. (91.5 meters) in one or the other of the sections, but it very rarely occurs during daylight hours. Most drivers using the facility are thoroughly familiar with the roadway, only a small minority - about 15 percent - are transient drivers.

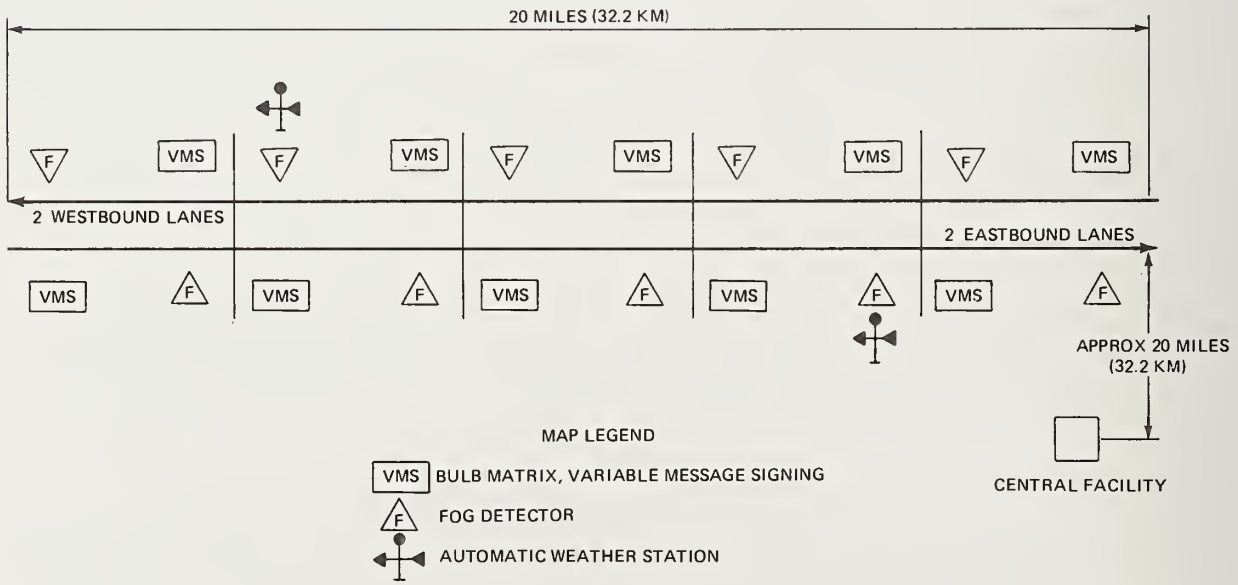


Figure 10. Medium Length System - Problem Area

In addition to the fog problem, the roadway is subject to icing conditions on the four interchange overpasses; although this occurs primarily during the winter months, while the fog is primarily during spring and fall, there are some occasions when both are present.

The reduced visibility accident history for the roadway has been worse than normal compared to other similar roadways in the state, but there have been no spectacular rear end collisions.

No requirements exist for congestion or incident monitoring on the roadway, since congestion levels seldom if ever reach significant levels.

(e) Medium Length - Medium MON

The scenario for this problem is identical with the previous one except that the fog problem is more moderate, with visibility more likely to be in the 300-1000 ft. (91.5-305 meters) range during the fog episodes.

In this scenario, icing does not occur and only a small percentage (10-15%) of the motorists who use the facility are transients, the rest being familiar with the area.

(f) Medium Length - Low MON

This scenario is identical with the medium MON scenario except for two conditions: fog is light when it does occur, and the AADT on the facility is in the neighborhood of 8,000 vehicles per day.

(g) Long System - High MON

The problem area contains two more or less parallel roadways separated by a mountainous region (Figure 11). The roadways skirt both sides of the mountains and join at both ends of a stretch about 25 miles (40.2 Km) long. The entire problem area is about 50 miles (80.4 Km) in length.

The surrounding countryside is arid and subject to frequent massive dust storms, and high winds. Although the direction from which the storms come is known, the exact location of the reduced visibility condition cannot be predicted in advance - the best that can be obtained is an hour or two of warning of the possibility within a fairly large geographic region. Due to the length and remoteness of the problem area, patrols through the area are infrequent. Occasionally convoys have been used with some success, when conditions are not too bad. The existence of an alternate route has led to suggestions that the affected roadway on the windward side of the range of mountains should be closed and traffic should be diverted to the leeward side of the range. This suggestion receives support from the fact that during the dust storm months a large fraction (25%) of the AADT of 10,000 vehicles per day consists of transient motorists who are unfamiliar with the area.

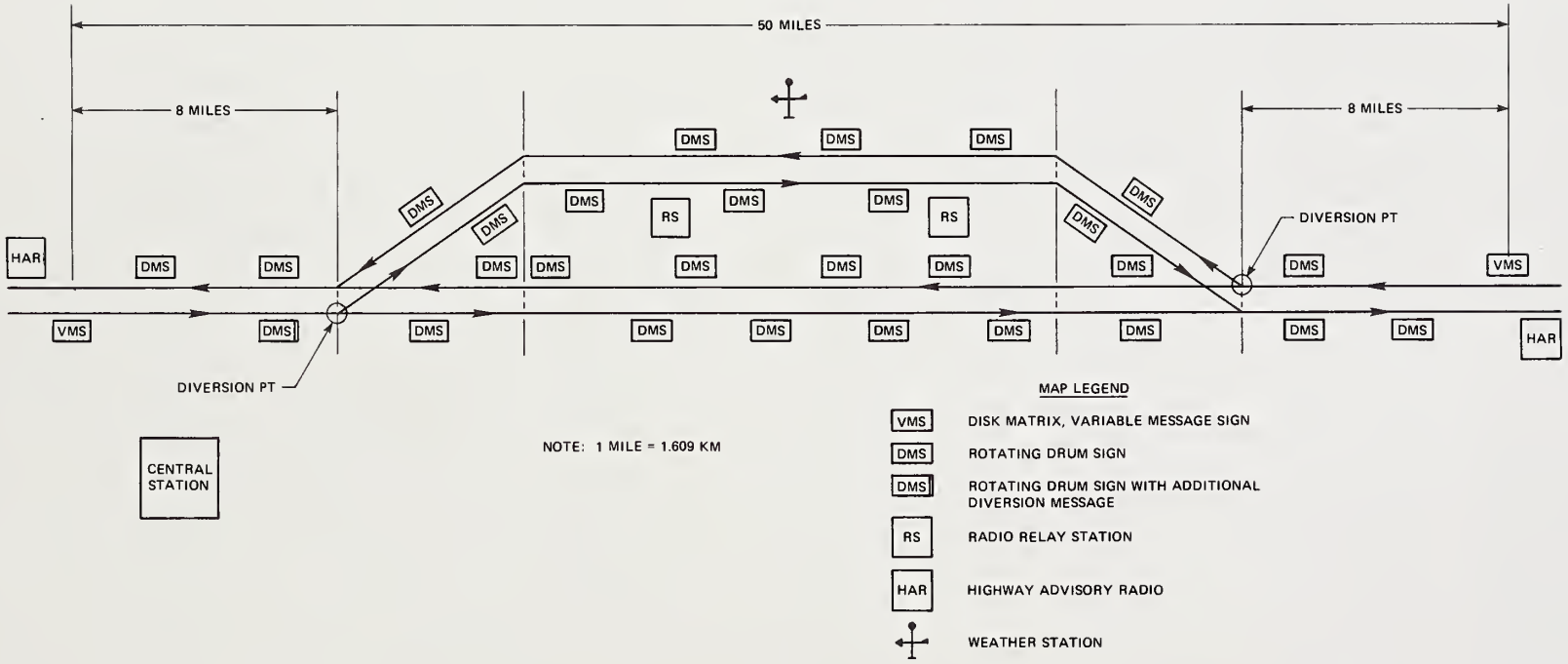


Figure 11. Long System - Problem Area

(h) Long System - Medium MON

The scenario for this location is similar to that of the high MON situation, except that the loss of visibility caused by the dust storms is not as great. Visibility is seldom less than 300 ft. (90.5 meters).

In addition, wind speeds are not high enough to constitute a problem to motorists.

In this scenario, only a small fraction of the motorists are transient.

(i) Long System - Low MON

This is identical to the scenario above, except that the AADT is lower -- 4000 vehicles per day.

2. Problem Area Characteristics

The User Guidelines (Section 3-5) describes the list of fourteen problem characteristics or system descriptors, and how these are coded in order to make decisions concerning system elements. These procedures have been followed in constructing the table of system descriptors for the nine system scenarios, shown in Table 15.

For example, the third descriptor in Table 15 is "Patrol Frequency". This is coded "I" for all nine systems, since the scenarios for all nine describe them as being in remote areas, where the likelihood of observing a significant change in reduced visibility in time to take credible action is small.

3. Selection of System Elements

The User Guidelines (Section 3-5) provide a step-by-step procedure for selecting system elements, using the problem area characteristics.

These procedures have been followed in selecting the nine system configurations shown in Table 16.

During the system configuration process, certain tradeoffs were made (e.g., to select a communications medium or a communication technique) whose outcome depended on assumptions concerning existing resources. For example, in the case of the point system in Table 16, radio was selected as the communication medium because of the assumption that no conduit or cable resources existed at the site. When the costs of trenching, jacking and cable procurement were compared with implementation costs for radio communications, the latter medium was clearly the better choice. Other factors which might have affected the choice, such as availability of radio bandwidth, or FCC licensing requirements for nonvoice radio communications, were not considered.

Similarly, a trade-off was made between the use of improved passive delineation and the use of convoys plus broadcast radio for the long system, low MON

TABLE 15. SYNTHESIZED SYSTEMS CHARACTERISTICS

	Point System			Medium System			Long System		
	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo
1. AADT Category	III	II	I	II	II	I	II	II	I
2. Size	P	P	P	M	M	M	L	L	L
3. Patrol Frequency	I	I	I	I	I	I	I	I	I
4. DIV/RD CLOS Feasibility	N	N	N	N	N	N	Y	Y	Y
5. RV Intensity	D	M	L	D	M	L	D	M	M
6. Daylight RV Prob.	N	N	N	N	N	N	N	N	N
7. Location Predictability	P	P	P	P	P	P	U	U	U
8. Time Predictability	U	U	U	U	U	U	M	M	M
9. CONG/INCID Detection & Control	N	N	N	N	N	N	N	N	N
10. Special Events	N	N	N	N	N	N	N	N	N
11. Traffic Control for Rdwy. Const.	N	N	N	N	N	N	N	N	N
12. Transient Driver Factor	N	N	N	N	N	N	Y	N	N
13. Speed Uniformity Requirement	Y	N	N	N	N	N	N	N	N
14. Other Weather Problems	Y	N	N	Y	N	N	Y	N	N

environment. The decision was in favor of convoys plus broadcast radio because of the excessive cost of procuring and maintaining a delineation system of such great length.

Figures 12, 13 and 14 are block diagrams of the point, medium length and long system configuration, respectively.

b. SYSTEM COSTS

The User Guidelines (Section 3-5) provide unit cost tables and step-by-step procedures for computing system implementation costs. These procedures have been followed in preparing the itemized cost tables (Appendix G of this volume) for each of the nine systems, using the system layout diagrams shown in Figures 9, 10 and 11.

TABLE 16. SYNTHESIZED SYSTEM CONFIGURATION

System Element	SYSTEM CLASSIFICATION								
	Point System			Medium Length			Long System		
	High	Med	Low	High	Med	Low	High	Med	Low
1. Improved Passive Treatment	X	X	X	X	X	X			
2. Convoy									X
3. Automatic RV Surveillance	X	X		X	X				
4. Dynamic Signs (Fixed)	X	X		X	X		X	X	
5. Dynamic Signs (Transportable)									
6. Automatic Vehicle Surveillance	X								
7. Highway Advisory Radio							X		
8. Weather Station	X			X			X		
9. Broadcast Radio							X	X	X
10. Active Motorist Guidance									
11. Communication Technique	TDM	TDM		TDM	TDM		TDM	TDM	
12. Communication Medium	Radio	Radio		Radio	Radio		Radio	Radio	
13. Data Process	Prog. Micro-proc.	Hard-wire Micro-proc.		Mini-com-puter	Prog. Micro-proc.		Mini-com-puter	Prog. Micro-proc.	

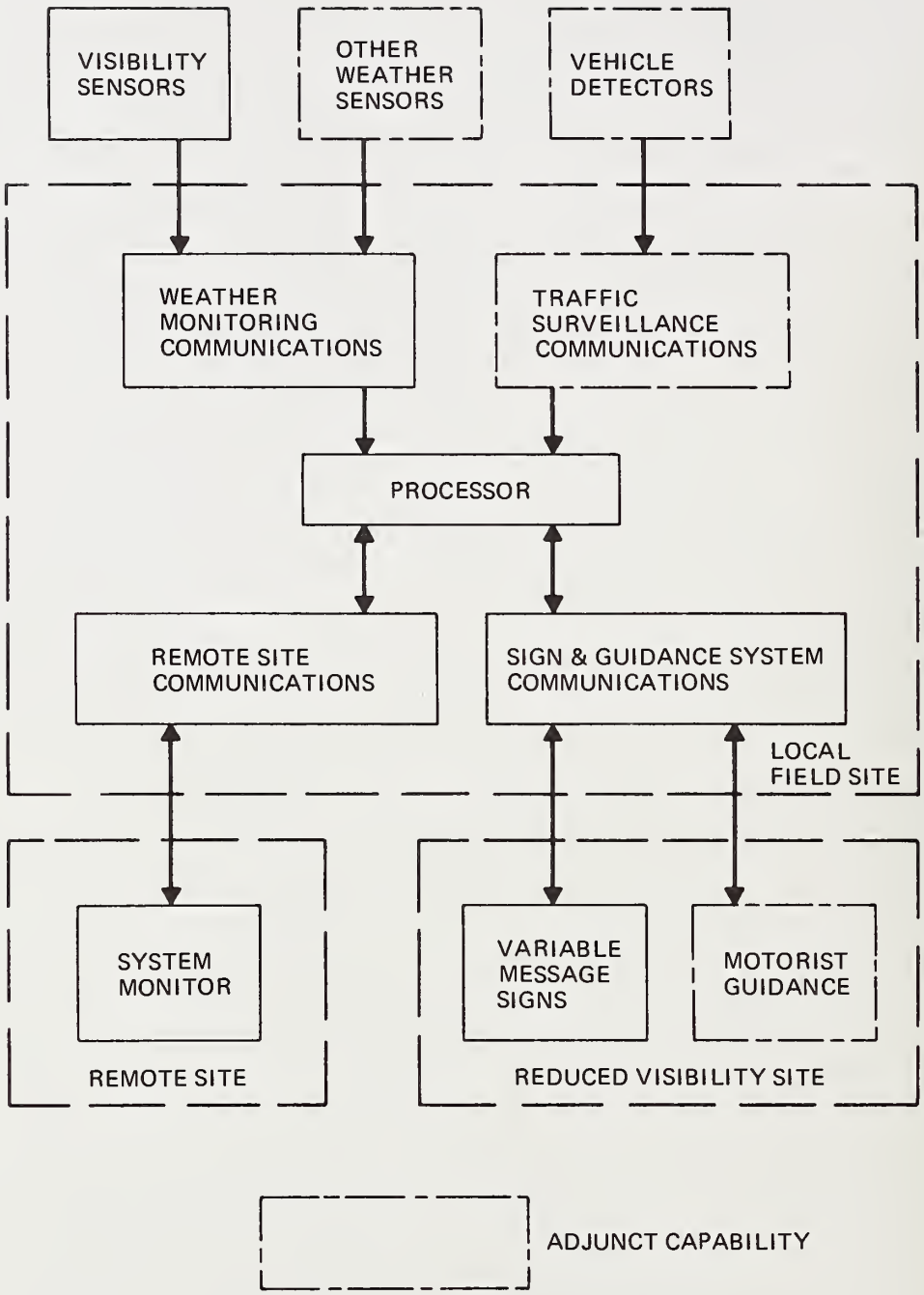


Figure 12. Point System Block Diagram

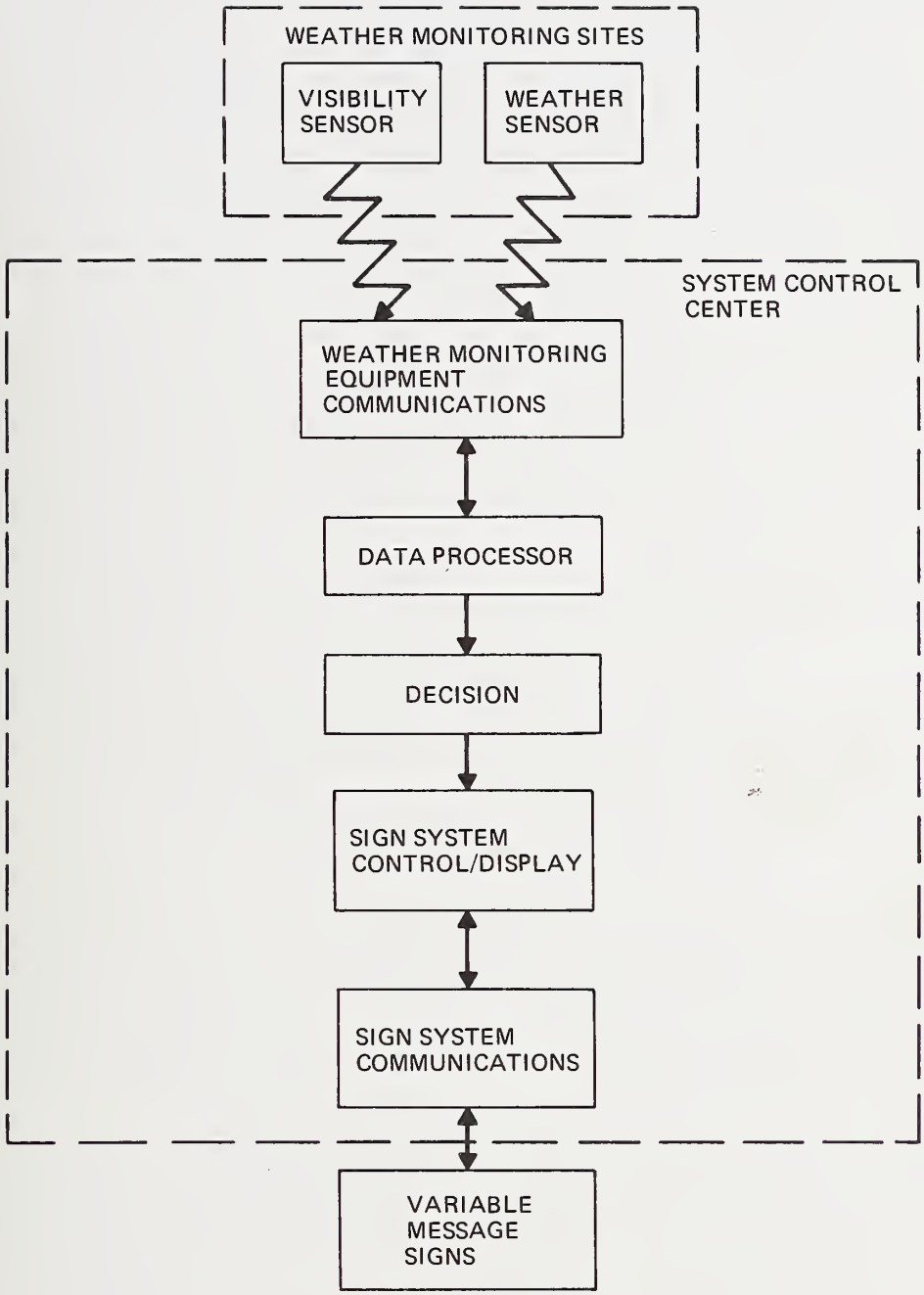


Figure 13. Medium Length System Block Diagram

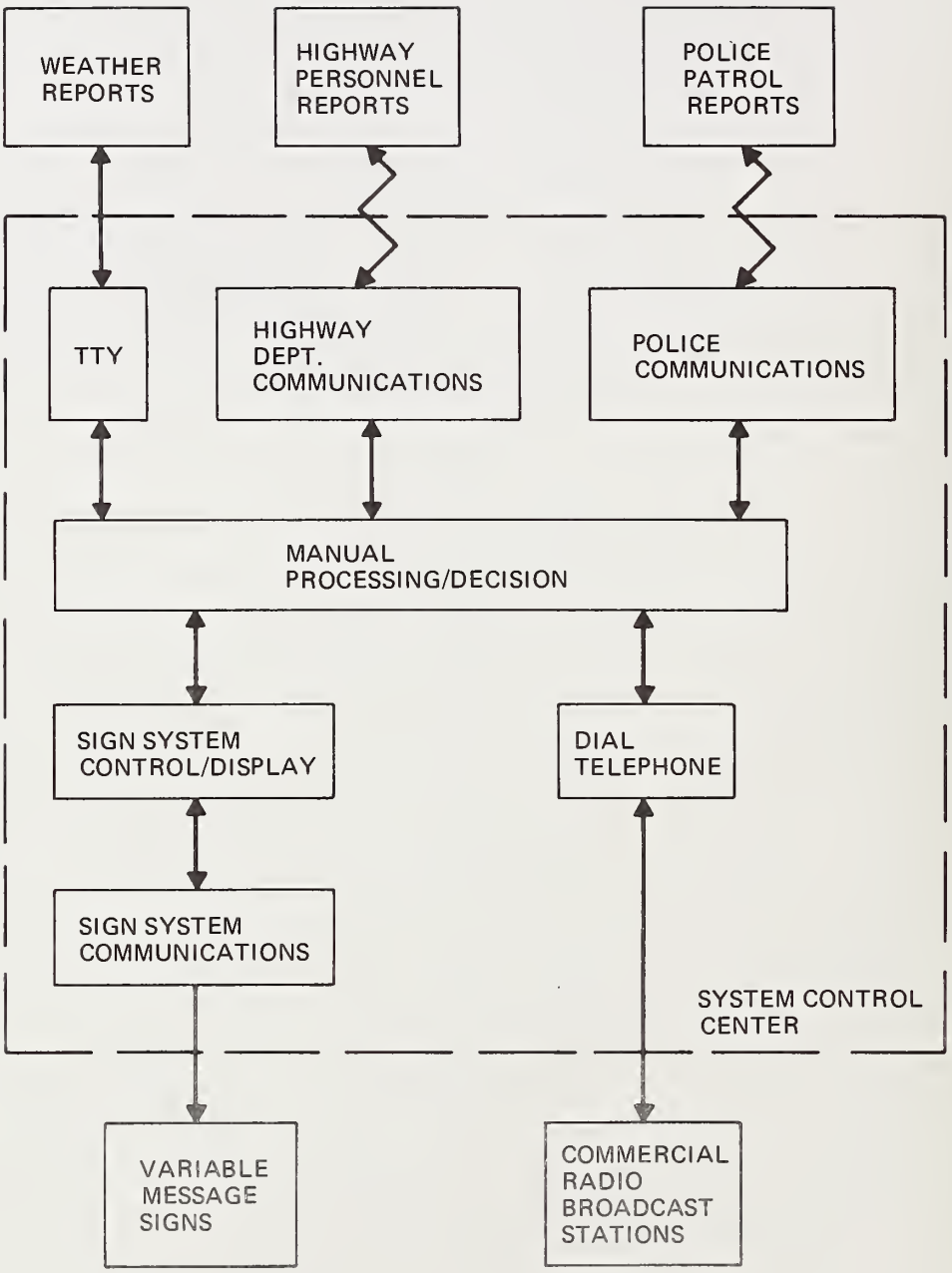


Figure 14. Long Length System Block Diagram

c. SYSTEM UTILITIES

Procedures for computing system utility when the system elements are known and the measure of need is known are given in the User Guidelines (Section 3-5). These procedures were followed in preparing Table 17, which shows the incremental utility for each system element of the nine systems.

d. SUMMARY AND CONCLUSIONS

Figure 15 presents a summary of the system costs and utilities as a function of length, with MON as a parameter.

These three curves provide rough estimates of the cost and utility which can be expected for a system of given length with a given MON environment.

1. Costs

System costs for the low and medium MON environments increase roughly proportional to length at first, then do not change significantly for the longer system installations. This is partly the result of some of the assumptions made in configuring the systems, but it also reflects two factors which probably are characteristic of almost all long systems:

- The exact location of reduced visibility within a very long problem area will not be known accurately enough to use automatic surveillance effectively.

- The length of the system makes the use of high quality passive delineation, in the form of reflective roadway markers and roadside paddles, very costly. This is especially true if the reduced visibility locations are so variable that the entire length of the roadway must be done.

2. Utility

For low MON systems, the utility is more or less independent of length, reflecting the fact that passive treatment of the roadway with delineation etc. has about the same utility value as the use of convoys. There is a slight decrease of utility for long systems because the convoy treatment and broadcast radio techniques used in the low MON environment, although effective when they are activated, are not available 24 hours-a-day, 7 days-a-week, as are the delineations.

For medium and high MON environments, the utility for long systems is lower than it is for shorter systems, reflecting the fact that special delineation and automatic RV surveillance control cannot be used effectively, because of the length and unpredictable location problems.

TABLE 17. SYNTHESIZED SYSTEM UTILITIES

	Point System			Medium Length System			Long Length System		
	Low	Med	High	Low	Med	High	Low	Med	High
1. Passive	417	334	282	417	334	282	-	-	-
2. Convoy	-	-	-	-	-	-	-	-	-
3. RV Surveillance	-	17	39	-	17	39	-	-	-
4. Dyn Sign	-	109	132	-	109	132	-	109	132
5. Auto Vehicle Surveillance	-	-	-	-	-	-	-	-	-
6. HAR	-	-	-	-	-	-	-	-	22
7. Weather Station	-	-	6	-	-	6	-	6	6
8. Broadcast Radio	-	-	-	-	-	-	130	130	130
9. Act. Motorist Guidance	-	-	-	-	-	-	-	-	-
10. Hard-wire Microprocessor	-	22	-	-	-	-	-	-	-
11. Programmable Microprocessor	-	-	167	-	149	-	-	149	-
12. Minicomputer	-	-	-	-	-	184	-	-	184
Utility	417	482	624	417	608	643	366	394	474
Cost ($)	32K	271K	455K	325K	752K	1,462K	290K	792K	1,894K

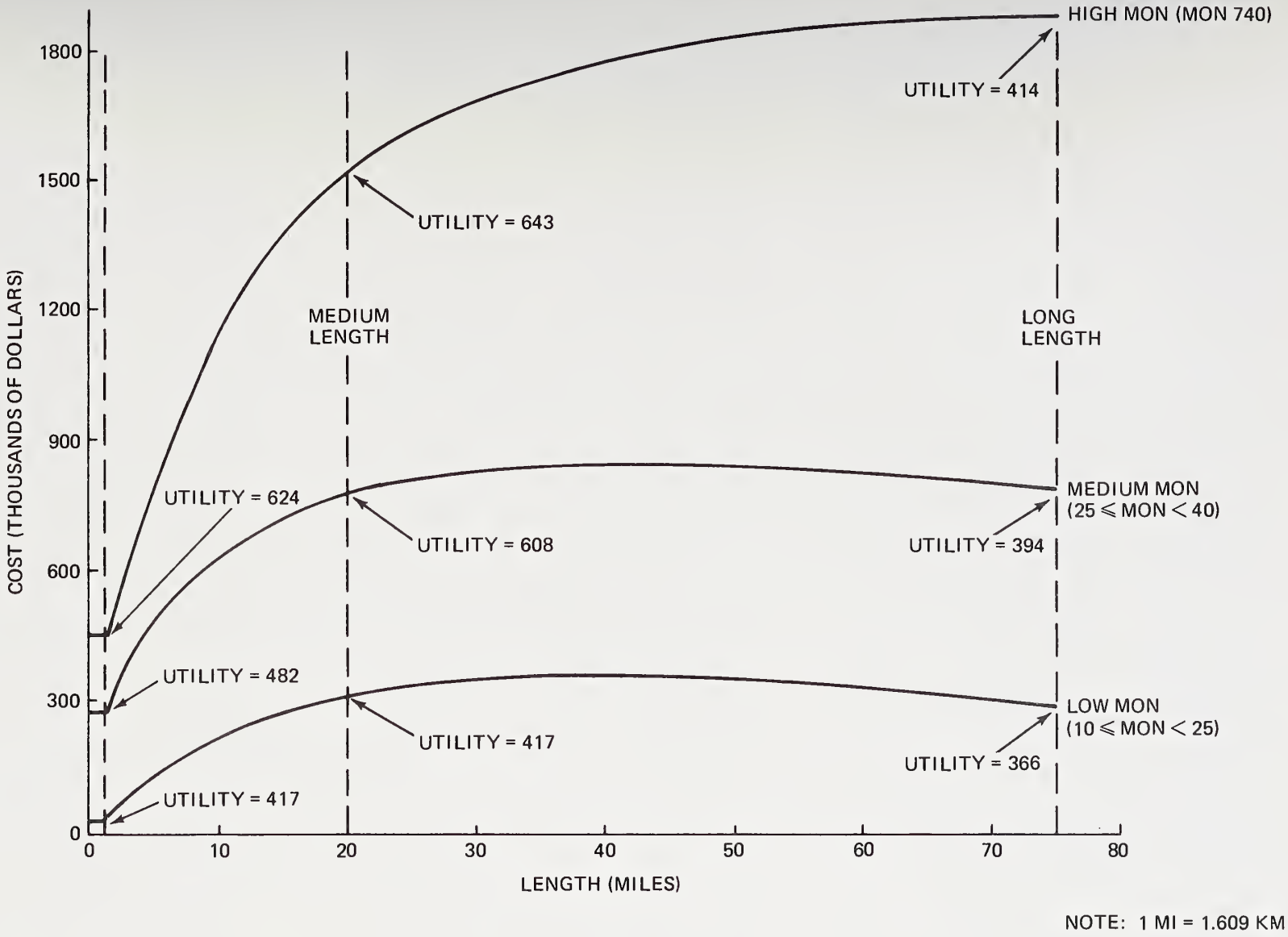


Figure 15. Synthesized System Costs and Utilities

3-5 TASK H: GUIDELINES

The objective of this task is to prepare comprehensive guidelines for highway agencies detailing costs, benefits and recommendations for different categories of reduced visibility guidance systems for different geometric, traffic and environmental conditions.

a. APPROACH

During the course of the study, two approaches to the guidelines were considered.

The initial approach was to use the insights obtained during the system evaluation (Tasks E and F) to define what might be called a "library" of candidate systems for the guideline user. These systems would range from very simple, completely passive ones to highly complex, fully automated dynamic systems. The user would select one or more of the systems from the "library" with the aid of guidelines based on the characteristics of his problem area. Each system would be provided with cost estimates and utility estimates so that comparisons between systems could be made.

However, during the course of the study, it became apparent that the library of candidate systems, which was refined from the experience gained in evaluation, did not include enough variety and did not accommodate itself adequately to the use of judgement on the part of the user. Therefore, the library was replaced by a guidelines procedure which allows a greater degree of flexibility on the part of the user in selecting system functions and equipment to match his need.

The procedure consists of three interrelated steps which lead to the selection of candidate systems for a problem area:

- Computation of a measure-of-need (MON) for the problem area
- Preparation of a group of characteristics which describe the problem area in reduced visibility terms
- Use of the MON and the characteristics to make a series of decisions as to the functions the system should perform

1. MON

Computation of a measure of need for the problem area has been discussed in Section 3-3. In the guidelines procedure, the MON serves to direct the user to one of three utility charts which give him the utility of the elements which he has selected, for the environment described by the MON.

2. Problem Characteristics

The experience gained in evaluation (Tasks E and F) provided insight into the relationship between the environmental, geometric and traffic parameters of the problem and the design of a system to cope with reduced visibility problems. (See Appendix F.)

Specifically, it resulted in the definition of the list of fourteen problem characteristics or descriptors shown in Table 18. These descriptors constitute the smallest set of problem characteristics[1] which make it possible to distinguish uniquely between systems with different functions. Table 18 shows the part of the system design process which is affected by each of the descriptors. For example, the AADT impacts decisions concerning the following functional elements:

- Transportable dynamic signs
- Automatic vehicle surveillance
- Active motorist guidance

The impact takes the form, in the guidelines, of specific criteria for making decisions in these areas. The criteria are based on the results of experience gained during the systems evaluation task. For example, automatic vehicle surveillance is not recommended unless a specific set of conditions exists in the problem area, one of which is an AADT high enough to require automatic vehicle surveillance for other reasons in addition to reduced visibility problems. (The other conditions which affect the choice of automatic vehicle surveillance are indicated by crosses in the column under the heading of "Automatic Vehicle Surveillance" in Table 18.)

3. Design Decision Tree

The third element in the guidelines procedure consists of a design tree (Figures 16 and 17) which guides the user through a series of decisions which determine the functional nature of his system. First, the major system decisions are made (Figure 16). These involve the following functions:

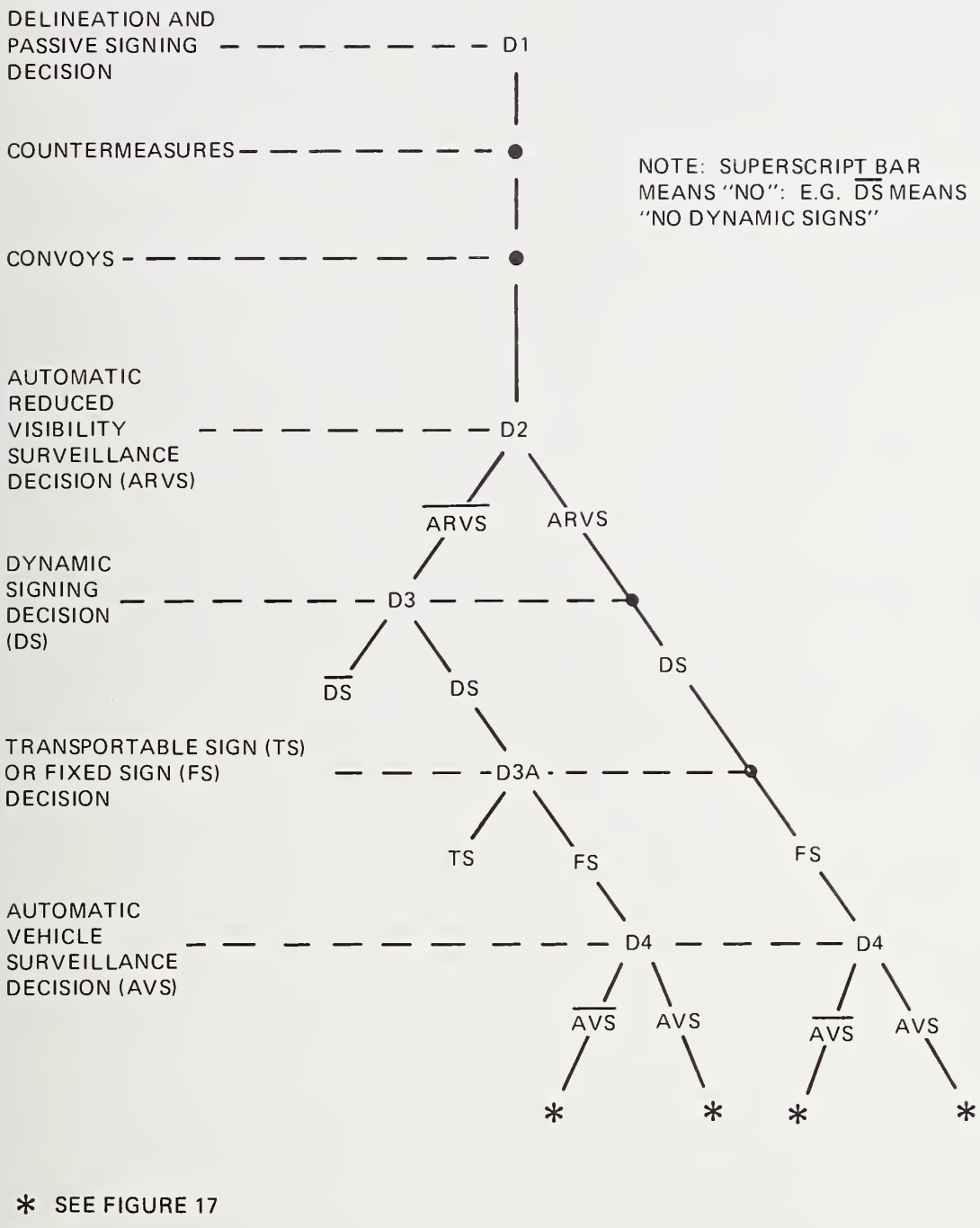
- Passive treatment of the area
- Countermeasures
- Use of convoys
- Automatic reduced visibility surveillance

---

[1] The MON index uses some of the same characteristics such as AADT and size but the information is "compressed" into a single number indicative of how badly a system is needed. Thus, two problem areas may have the same numerical value of MON, but may need entirely different systems.

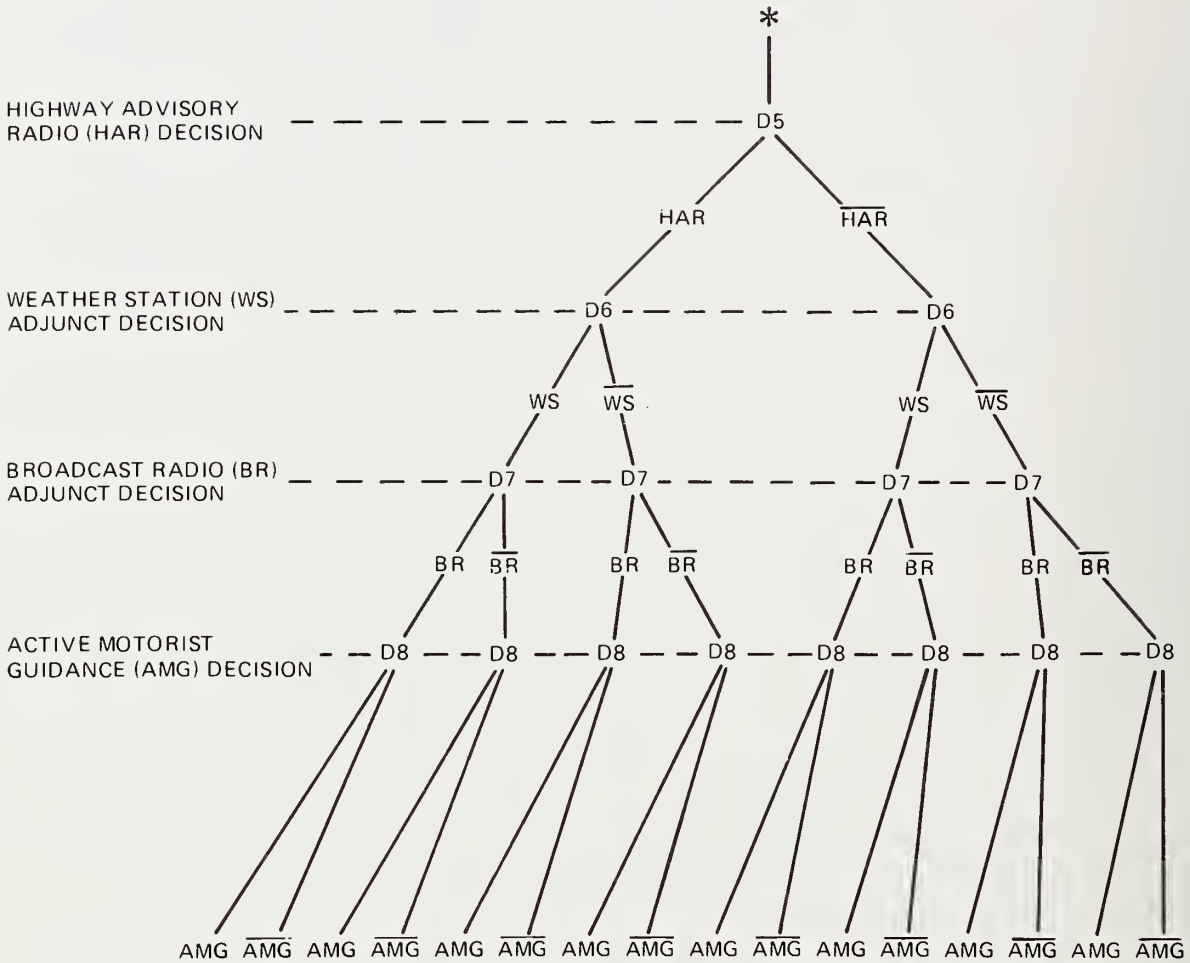
TABLE 18. PROBLEM DESCRIPTORS AND SYSTEM ELEMENTS

Problem Descriptor	Auto RV Surveillance	Dynamic Sign	Transportable Sign	Auto Vehicle Surveillance	Highway Advisory Radio	Weather Station	Broadcast Radio	Active Motorist Guidance
1. AADT			X	X				X
2. Size	X		X	X	X		X	X
3. Patrol Frequency	X						X	
4. Diversion/Closure Feasibility					X			X
5. RV Intensity	X	X	X	X	X		X	X
6. Daylight RV Problem								X
7. Location Predictability	X		X			X	X	X
8. Time Predictability			X				X	
9. Congestion/ Incident Control			X	X				
10. Special Events			X	X				
11. Construction/ Maintenance			X	X				
12. Transient Drivers					X			
13. Speed Uniformity				X				
14. Other Weather Factors						X		



* SEE FIGURE 17

Figure 16. Design Tree for Major System Elements



* SEE FIGURE 16

NOTE: A SUPERSCRIPT BAR MEANS "NO"; FOR EXAMPLE, "$\overline{HAR}$" MEANS "NO HIGHWAY ADVISORY RADIO"

Figure 17. Design Tree for Adjunct System Elements

- Dynamic signing (fixed location or transportable)
- Automatic vehicle surveillance

Then, the secondary or adjunct system decisions are made (Figure 17). These involve the following functions:

- Highway advisory radio
- Weather station
- Broadcast radio
- Active motorist guidance

Each decision is made by the guideline user on the basis of the problem descriptors for his problem area. The guidelines will thus provide the user with a set of functional elements which is compatible with this description of the problem area. The same set of problem descriptors will always yield the same set of functional elements. Diversity is built into the procedure by permitting some flexibility in the use of descriptors. Some of these are designed to be used somewhat loosely for the following reason.

It will often be the case that a precise value for the descriptor cannot be given without acquiring more data than is reasonable for this stage of design. An example of this situation is the "location predictability" descriptor (No. 7 in Table 18). The degree of predictability of the precise location of the reduced visibility surveillance techniques is called into question. Very rarely do enough data exist to allow the user to answer this question with a high degree of confidence. Usually, an educated guess must be made, which relies on the judgement of the guideline user.

b. GUIDELINE FORMAT

The guidelines are structured around four basic steps. (See Figure 18.):

- Assessment of the problem
- Problem characterization
- Configuration of candidate systems
- Comparison of candidate systems

1. Problem Assessment

Consists of instructions for assembling data and computation of measure of need. The data include all the accident, environmental, vehicular and roadway geometrics necessary to compute the measure of need. They also include a compilation of existing resources both physical and manpower, and they include any requirements which may have a bearing on the installation of a reduced visibility guidance

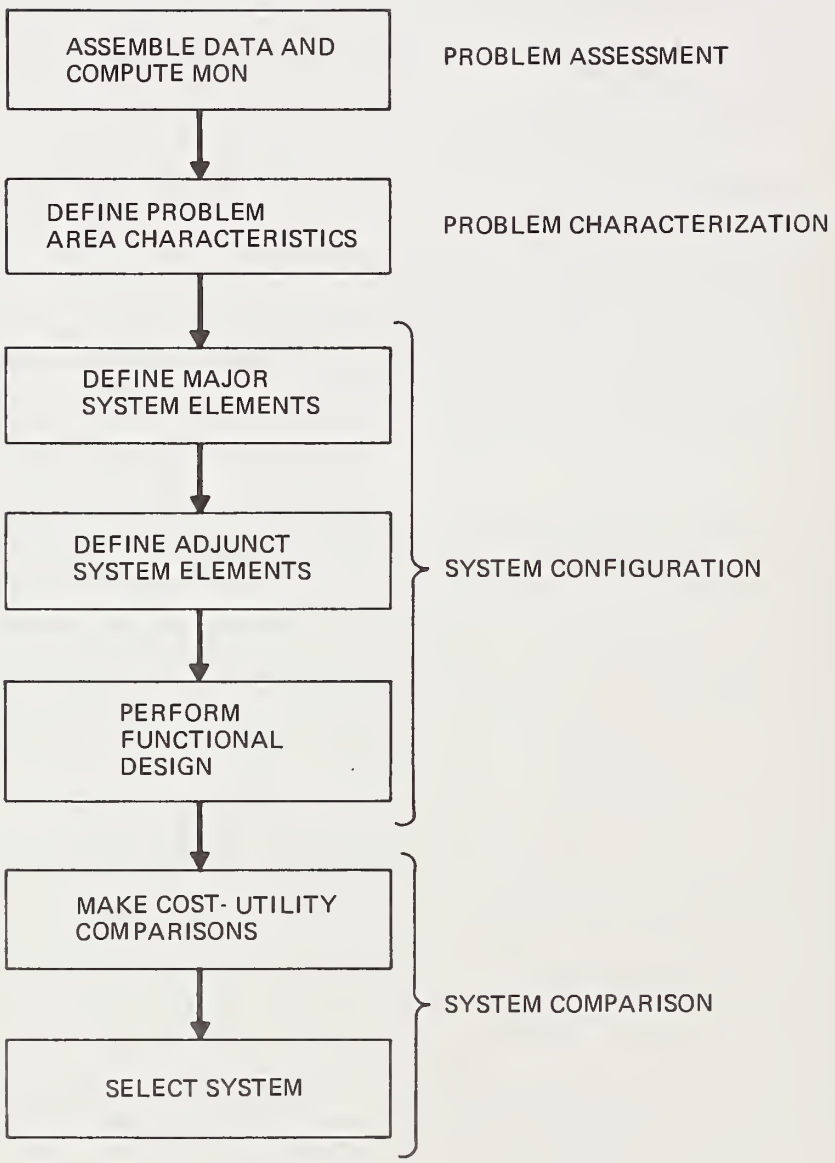


Figure 18. Basic Structure of Guidelines Procedure

system (e.g., elimination of geometric or other hazards, requirements for congestion control, public demand for improvement of driving conditions, etc.). Following the data assembly, the measure of need for the problem area is computed.

2. Problem Characterization

Consists of providing coded descriptions of fourteen characteristics concerning the problem area (see Appendix F). The coded descriptions provide the criteria by means of which system design configuration is chosen in the guideline procedure.

3. Candidate System Configuration

Consists of selecting system elements according to clearly specified criteria using the problem descriptors from the previous step.

When all elements have been selected, the user is provided with guidelines for:

- Laying out system elements (physical configuration)
- Selecting a communications system and medium, if required[1]
- Selecting a data processor and peripherals, if required[1]

4. Comparison of Candidate Systems

Consists of estimating costs and utilities for each of the candidate systems which the user has generated as a result of the previous steps. Unit costs for each of the elements which make up the system are provided in a guidelines appendix. With the system's physical configuration (i.e., number, kind and location of equipment sites), the user is able to compute total system capital, maintenance and operation costs.

The user is also provided with a set of utility tables which relate the measure-of-need, the system elements he has chosen, and each element's utility. This utility is pre-calculated for each element from a basic utility model. The total candidate system utility is computed by summing the utilities of the separate elements for the given measure of need. The user then computes the utility-to-cost ratio for each candidate and selects, provisionally, the candidate with the highest ratio. The choice is then subjected to a final review in the light of funds which are available.

- - - - - -

[1]The guidelines procedural format makes it unnecessary to go through the later, more complex steps of the process if the initial decisions have resulted in a very simple system. Thus, for example, a user who finds that he needs only passive delineation will be routed around those parts of the guideline procedure which have to do with surveillance, signing, communications and data processing.

Appendix A
LITERATURE SUMMARY
INTRODUCTION

This appendix presents the results of a literature search on reduced visibility detection and warning systems performed as part of the research project entitled Effectiveness of Reduced Visibility Guidance Techniques. The literature search was divided into two parts. Part I consists of obtaining pertinent references from the files of the following organizations:

- Highway Research Information Service - HRIS (National Research Council, Washington, D.C.)
- National Technical Information Service - NTI Search (US Department of Commerce; Springfield, Virginia)
- National Highway Traffic Safety Administration (US Department of Transportation, Washington, DC)
- National Safety Council Literature (SSM Search) (Chicago, Illinois)
- Smithsonian Science Information Exchange (Washington, DC)
- Franklin Institute Research Laboratories (Philadelphia, Pennsylvania).

Key word descriptors were supplied as part of the computerized retrieval strategy. A sampling of the code words used is as follows:

- Fog
- Snow
- Dust
- Rain
- Countermeasures
- Visibility
- Accident prevention
- Traffic safety
- Smoke
- Ice
- Frost
- Sand
- Reduced visibility
- Vehicle guidance aids
- Detectors
- Warning indicators
- Hazard warning displays
- Cost/benefit analyses
- Remote sensing
- Effectiveness evaluation.

The output document packages of the literature search were reviewed by the Project Staff to identify those references which would be of importance to the research project. Private communication with the study Task Force members and federal and state highway organizations were also used to identify other pertinent literature which did not appear in the formal literature search.

Part II of the literature search consisted of acquiring articles identified by references and examining them for their usefulness to project research objectives. A total of 94 reference documents were considered to be of primary importance. These documents were reviewed and relevant information was digested and abstracted into a standard format. Digests of the primary references are presented in Sections A1 through A5. Secondary literature is listed in Section A6 and a literature index (refer to Section A7) is provided.

Document titles are listed as part of the table of contents and form the sub-paragraphs of this index. The literature index contains a listing of the abstracted reference documents identified under key words or phrases arranged in alphabetical order. Reference numbers were assigned to the primary literature digests to facilitate the use of this volume, and are included with the title of each document in the table of contents. Each reference number contains three characters representing the location of the digest in the text (eg., reference III8A refers to the digest located in Section A3, paragraph 3-8a).

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Section A1

DESCRIPTION OF REDUCED VISIBILITY ENVIRONMENTS

A1-1 INTRODUCTION

The literature in this section describes the nature of the reduced visibility environment.

A1-2 GENERAL

Miscellaneous topics are included in this paragraph.

a. I2A - HORIZONTAL VISIBILITY AND THE MEASUREMENT OF ATMOSPHERIC OPTICAL DEPTH OF LIDOR

- APPLICABILITY: Determination of visibility distances for a variety of atmospheric conditions
- DOCUMENT AUTHOR(S), SOURCE DATE: Cohen, A. Applied Optics Vol. 14, 12 December 1975
- DOCUMENT IDENTIFICATION NO. None

This paper describes a generalized treatment of the atmospheric visibility distances for a variety of atmospheric conditions. In the development of the formula for the visibility distance, it is shown how a series of assumptions made in the early work of Koschmieder (Beitr. Phys. Atmos. 12, 33 (1924)) can be reduced to a single assumption covering more atmospheric conditions. Special attention is paid to the cases in which the extinction coefficient is wavelength-dependent. It is shown that neglecting such a dependence may produce errors as large as 20 to 100 percent, especially when long visibility distances are considered. The use of a dye-laser radar for the remote sensing of visibility distances is described and discussed.

A1-3 FOG

The effects of fog on reducing visibility are discussed in the following pages.

a. I3A - FOG AND ROAD TRAFFIC

- APPLICABILITY: Description and forecasting of fog, incidence of fog, effect of fog on visibility, effect of fog on road traffic and accidents, remedial measures, economics of remedial measures

- DOCUMENT AUTHOR(S), SOURCE, DATE: Moore, R.L. and Cooper, L. Transport and Road Research Laboratory Department of the Environment, England TRRL Report LR 446, 1972

- DOCUMENT IDENTIFICATION NO. LR 446

Thick fog occurs in Great Britain approximately ten days each year: it impedes traffic and some dramatic accidents occur on high speed roads. Overall some two percent of all road casualties occur in foggy weather. Although the total number of motorway fog accidents is small, accidents per kilometer are more numerous than on other roads and more serious. The physics of fog and the prospects of reducing the number of fog accidents by fog dispersal, radar are discussed. Current valuations of accidents costs are used to estimate the additional expenditure on vehicles and roads that might be justified assuming that it resulted in a halving of fog accidents. It is probable that the most worthwhile countermeasure to fog accidents may be found in systems of traffic control that have a wider application than only in fog.

b. I3B - MINIMIZE THE HAZARD OF RESTRICTED VISIBILITY IN FOG - WITH DISCUSSION

- APPLICABILITY: Nature of fog and its formation, effects of fog on driving and accidents, fog abatement techniques, motorist guidance systems

- DOCUMENT AUTHOR(S), SOURCE, DATE: Schwab, R.N. Heiss, W.H. - discusser Hofstetter, D. - discusser Highway Research Board, Special Report on Highway Visibility, July 1972

- DOCUMENT IDENTIFICATION NO. N134, 73. pages 19 to 27

This paper describes the nature of fog and its formation, the effects of fog and accidents, current fog abatement techniques, and possible guidance systems to aid drivers in minimizing the hazards encountered in fog. Studies have revealed that for conventional roads, fog (which reduces the visual range to less than 3,300 feet (1006 m) reduces the accident rate by six to ten percent with the largest reduction in the more severe categories of accidents. This effect is attributed to the driver's awareness of fog as a hazard. Studies on freeways, however, reveal that fatality rate for fog accidents is twice that of non-fog accidents; the probability of multiple-vehicle accidents is greater; and fog does not have much effect on the mean number of vehicles per accident because there were also more single vehicle accidents in fog. Fog abatement techniques reviewed include dry-ice seeding, reducing industrial pollution, and thermal, electrical and mechanical fog dispersal techniques. The limited utility of portable dispersal equipment, and natural vegetation barriers that prevent the drifting of shallow fogs are also discussed. Directional types of fixed-lighting systems

have proved effective in providing guidance in nighttime fog. Reflectorized pavement markings and rear vehicle lighting systems are ineffective in daytime fog. Variable message signs that warn drivers of fog conditions ahead and indicate speed requirements are considered the most desirable. An advisory system that will inform drivers of the status of other vehicles' speeds on the road ahead beyond the limit of the drivers' sight is currently being developed. The variable nature of different types of fog and the need to study the specific problem is stressed in the discussion.

c. I3C - PHYSICS AND DISTRIBUTION OF FOG

- APPLICABILITY: Fog classification, contributors in fog formation, general theory of visual range
- DOCUMENT AUTHOR(S), SOURCE, DATE: Kocmond, W.C., Pilie, B.J., Badie, W.J. ITTE, California University, Berkeley Proc., 2nd Annual Symposium December 1969
- DOCUMENT IDENTIFICATION NO. None

A fog classification system is outlined. The horizontal visual range in fog is most important to the automobile driver, and for this reason only dense fogs are likely to have any effects on his behavior in traffic. It is shown that a variety of mechanisms involving energy, heat, and moisture contribute to the formation of fog. Pertinent condensation processes are discussed for additional insight into the mechanisms of fog formation. The basic concepts of atmospheric visibility are described. The general theory of visual range is presented with the visibility equation. The theory indicates that visibility can be improved in fog by either of two actions: (1) the decrease of liquid water content, and (2) the drop size distribution can be altered to cause the water to be concentrated into a few large drops rather than a large number of small droplets, so that the average drop radius is increased. Data are summarized on the frequency of fog formation. Fog is most frequent and quite local in nature along the west coast, in the Appalachian Mountains, and along the New England coast.

A1-4 DUST

This paragraph deals with the effects of dust on reduced visibility environments.

a. I4A - DUST STORMS

- APPLICABILITY: Dust storm mechanism and behavior, dust storm types, classification system used for predicting dust storm activity

- DOCUMENT AUTHOR(S), SOURCE, DATE: Idso, S.B. Scientific American October 1976

- DOCUMENT IDENTIFICATION NO. None

This article describes the nature of dust storms and the effect they have on man's environment. Photographs from satellites can reveal much information about the extent of dust storms and where they originate. The different types of dust storms are discussed with regard to their behavior and mechanism. The major regions in the world where the various types of dust storms are frequently generated are described. A study approach for dust storms is discussed which is based on studying the surface characteristics of deserts, such as the types of dune. Some of the factors that determine the size and form of dune bodies are known (e.g., the direction, strength and variability of the wind). Through the use of satellite photographs, a dune classification system has been developed that recognizes five basic patterns. The task of correlating the dust forms with patterns of wind and characteristics of dust storms is still in progress. Once this characterization process has been completed, scientists will be in a better position to make reasonable predictions of where and when dust storms may arise.

A1-5 SNOW

The effects of snow on reducing visibility are dealt with here.

a. I5A - MODEL TECHNIQUE FOR CONTROLLING SNOW ON ROADS AND RUNWAYS

- APPLICABILITY: Model techniques to predict the patterns developed by falling snow, wind tunnel study

- DOCUMENT AUTHOR(S), SOURCE, DATE: Theakston, F.H. Paper presented at the International Symposium on Snow Removal and Ice Control Research April 8-10, 1970 Highway Research Board, Special Report 115

- DOCUMENT IDENTIFICATION NO. None

Snow has always been a most difficult element to predict and to control in areas where there is heavy accumulation. An open channel water flume and models have been used to predict consistently the patterns developed by falling snow. Light, white sand is used to simulate snow. Various densities of snow storms are created within minutes, and qualitative analyses are made for remedial measures. A wind tunnel study is carried out to ensure positive results.

A1-6 RAIN

Reduced visibility conditions caused by rain are discussed here.

a. I6A - RAINFALL AND VISIBILITY - THE VIEW FROM BEHIND THE WHEEL

- APPLICABILITY: Rain, Visibility, Traffic Control, Passing Sight Distance
- DOCUMENT AUTHOR(S), SOURCE, DATE: Ivey, D.L.; Lehtipuu, E.K.; Button, J.W. Texas Transportation Institute, Sponsored by: Texas Highway Department, Interim Report, September 1973 to February 1975
- DOCUMENT IDENTIFICATION NO. Contract No. 1-10-70-135

The factors influencing wet weather accidents are complex, a fact readily ignored by many who would blame tire pavement friction for all our wet weather problems. A factor of significance is visibility, as influenced not only by rainfall intensity but to a great extent by traffic speed. This interim report presents a limited number of direct visibility observations and develops a framework useful in interpreting these data to determine the influence of reduced visibility on the operation of motor vehicles. Information from the literature shows the low probability of high intensity rainfalls. Conclusions concerning the hazard of passing maneuvers during rainfall of one inch (2.54 cm) per hour or more and the need to reduce speed under wet weather conditions are also presented.

Section A2

DRIVING BEHAVIOR AND ACCIDENT ANALYSIS

A2-1 INTRODUCTION

The literature pertaining to the effect of a reduced visibility environment on driving behavior and accident occurrence is presented in this section.

A2-2 FOG

The following abstracts deal with how fog affects driving behavior.

a. II2A - FOG, DRIVERS' REACTION AND ACCIDENTS IN CALIFORNIA

- APPLICABILITY: Fog accident study, stopping site distance in fog, driver behavior, approaches to the fog accident problem
- DOCUMENT AUTHOR(S) SOURCE, DATE: Theobald, D.J. ITTE, California University, Berkeley Proceedings 2nd Annual Symposium, Paper, December 1969
- DOCUMENT IDENTIFICATION NO. None

A four-year study was conducted of fog accidents in California to find possible remedial measures. One observation was that the stopping distance was not enough to be safe in fog. When driving in fog with a visibility of six or seven hundred feet, all the events and conditions must be appraised, decided, and acted upon in less than eight seconds if the vehicle is moving at 65 mph (104.6 km/hr). A second or two diversion at the wrong time makes a stopped vehicle or other obstruction unavoidable even with several hundred feet of visibility. Another aspect of accident problems that emerged was that while most of the accidents occurred during the morning peak hours, it was usually in the off-peak direction. One of the most discouraging findings was a realization that under most fog conditions, regardless of the control device used, drivers drove faster than what was considered a safe speed. The fog study conducted by the California Transportation Agency approached the problem from four aspects: the roadway, patrol activity, public information, and vehicle and equipment. The roadway study involved variable message speed signs, pavement markers, edge lines and colored lane lines. Of the four treatments, the variable message phase appeared the most productive. The second approach via increased exposure either of parked or of moving units of the California Highway Patrol showed that parked units in advance of the test site did cause a four to six mph (6.4 to 9.7 km/hr) reduction in mean speed under certain conditions, but under other variables of daylight and fog intensity, the patrol had no effect. The public information approach did not affect the characteristics of driving in the fog.

b. II2B - MOTORWAY ACCIDENTS IN FOG AND DARKNESS

- APPLICABILITY: Fog and nighttime accidents, accident analysis
- DOCUMENT AUTHOR(S), SOURCE, DATE: Johnson, H.D.
  Transport and Road Research Laboratory
  Department of the Environment, England
  TRRL Report LR 573
- DOCUMENT IDENTIFICATION NO. Report LR 573

Analyses have been carried out to assess the accident problem in fog and in darkness on the main motorways in the country (MI, M2, 7J, 7K, M6) between 1969 and 1971; about 80 percent of all accidents in the motorway network have been covered, and the various lengths have been broken down to make comparison between different locations. Accidents in fog totaled 192 in the three year period, making up four percent of the total; 129 of these occurred during daylight hours. Accidents were on the average more serious, with more casualties per accident, than those occurring in other weather conditions. About 45 percent of fog accidents and 22 percent of non-fog accidents occurred on about one-seventh (160 km) of the motorway network. Accidents in darkness totaled 1,801 (39 percent of all accidents) in the same period: 1,563 of these occurred on unlit motorways. Consideration of accidents on different lengths of road related to traffic volumes showed a range from 0.48 dark accidents per mile per year (.3 per km per year) on the more lightly trafficked sections to 3.86 dark accidents per mile per year (2.4 per kilometer per year) on the more heavily trafficked. In comparison, the range of accidents per kilometer during all hours was proportionately less, being 1.1 to 4.9. The larger differences in the numbers of dark accidents per km may be partly explained by the higher proportion of traffic flow at night on the more heavily travelled sections of the motorway.

c. II2C - A STUDY OF SOME ACCIDENTS ON MOTORWAY M4 IN FOG

- APPLICABILITY: Multiple collisions in fog, behavior of vehicles, speeds of vehicles, damage to vehicles, traffic flow and accidents, multiple collisions in clear visibility, survey questionnaires on driver accident experience
- DOCUMENT AUTHOR(S), SOURCE, DATE: Miller, M.M.
  Road Research Laboratory
  Ministry of Transport, England
  RRL Report LR55, 1967
- DOCUMENT IDENTIFICATION NO. Report LR 55

On 22 October 1965, a two-lane stretch of the M4 motorway between Slough and Maidenhead became fogbound, and many vehicles were involved in multiple accidents between 5 pm and 10 pm, when it was dark. A questionnaire was sent to 110 of the drivers of the vehicles involved asking them for their help in providing answers to a few questions. Fifty-three replied. Most drivers said they were in the fast lane and were attempting to keep vehicles ahead of them in sight. Driver's estimates of visibility and speed at which they were traveling differed considerably; from their answers, their estimates for the average speed were 27 miles per hour (43.4 km/hr) and, for the visibility in two-thirds of the incidents, under 12 yards (11 m). Some drivers said they were able to stop without colliding with the vehicle ahead but were then forced into it by the following vehicle. Most vehicles sustained only minor damage; the replies stated that thirteen people were injured, none seriously.

The results indicate that in fairly thick fog on the motorway many drivers are unable to gauge the distance between themselves and the vehicle in front of them, and their own speed; they do not allow sufficient spacing to stop when the vehicle in front stops suddenly.

Observations made on another night when the visibility was good and speeds were higher, again showed that drivers did not allow sufficient spacing to avoid a collision with the vehicle ahead if it stopped suddenly.

The results clearly indicate the need for further research into multiple collisions; in particular more knowledge is needed about the speed and spacing of vehicles at different traffic flow levels and visibility conditions both on motorways and other classes of road. The time it takes drivers to respond to stop lights and to recognize when the vehicle ahead has stopped without the operation of stop lights in different visibility conditions would also be worth investigating to provide information on better warning signals.

d. II2D - DRIVING IN FOG

• APPLICABILITY:	Driver behavior in fog
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Perchonok, K. Cornell Aeronautical Laboratory ITTE, California University, Berkeley Proceedings 2nd Annual Symposium Paper, December 1969
• DOCUMENT IDENTIFICATION NO.	None

Drivers are aware of fog as a hazard, but they do not overtly respond in ways other than with modest speed reductions. Traffic data from a rural highway show the speed reductions to be insufficient to preclude excessive overdriving. The data also shows a failure to minimize interactions with other vehicles. The accident data, however, suggests that these problems become less severe when the driver expects to interact with other vehicles. The problem is most severe under conditions of overconfidence associated with limited access highways.

e. II2E - SPEED PLUS FOG - THE DEADLY DUO

- APPLICABILITY: Vehicle speeds in fog, vehicle maintenance influence on accident potential, accident avoidance techniques
- DOCUMENT AUTHOR(S), SOURCE, DATE: Roper, W.L. California Highway Patrolmen Vol. 38, No. 1, January 1975
- DOCUMENT IDENTIFICATION NO. None

The need for proper vehicle maintenance and the role defects play in accidents are stressed, in addition to the role played by speed. Suggestions are made for safe driving in hazardous conditions. Specific accounts are given of multi-vehicle accidents which had icy or wet road conditions, fog, and speed as contributing causes. Suggestions are made regarding accident avoidance and survival, as well as brake, steering, and wheel defect detection. Emphasis is placed on skid control techniques.

f. II2F - THE EFFECT OF ADVERSE VISIBILITY ON DRIVER STEERING PERFORMANCE IN AN AUTOMOBILE SIMULATOR

- APPLICABILITY: Visibility requirements for good driver performance
- DOCUMENT AUTHOR(S), SOURCE, DATE: Allen, R.W. and McRaer, D.T., Systems Technology, Inc. Paper presented at SAE Meeting in Detroit, March 2, 1977
- DOCUMENT IDENTIFICATION NO. None

This paper describes a simulation experiment in which driving behavior and driver-vehicle system performance were measured over a range of visibility and roadway configuration variations. Driver dynamic response was reliably affected by variations in visibility and configuration. These effects were also reflected in system performance measures such as lane deviations. The results suggest minimum visibility requirements for the driver to maintain adequate steering control of a car under reduced visibility conditions.

Visual perception is critical in automobile driving to define the desired path and current status of the vehicle with respect to its surroundings. Roadways are marked or delineated in order to enhance the driver's visual perception, and vehicle and roadway lighting systems are provided to counteract the effects of adverse visibility conditions. In designing delineation and lighting systems, key considerations are the driver's perceptual requirements for vehicle navigation and control, and the effect of various environmental factors on the visibility of required visual cues. This paper addresses these considerations, with emphasis on the visual cues required for steering control along an unobstructed path.

A2-3 SNOW

The effects of snow on driving behavior are noted and discussed in this paragraph.

a. II3A - THE EFFECT OF LOW VISIBILITY ON THE PERFORMANCE OF VEHICLE OPERATIONS

- APPLICABILITY: Cold weather operations, ground vehicles, military mobility, mobility, motor vehicle operations, surface navigation, visibility, visual navigation, white-out
- DOCUMENT AUTHOR(S), SOURCE, DATE: Liston, R. U.S. Army Cold Regions Research and Engineering Laboratory Technical Report, August 1972
- DOCUMENT IDENTIFICATION NO. Technical Report 237

An experimental program to identify the relationship between visibility conditions and operator performance is discussed. Average speed in negotiating a controlled course is taken as the measure of operator performance. The method to measure visibility is discussed. It is shown that despite use of a contrived test course and artificially reduced visibility, the results appear valid. It is also shown that the relationship between conditions and average speed can be represented with a simple second order equation.

A2-4 RAIN

The following pages deal with the effects of rain on driving behavior.

a. II4A - RAINFALL AND VISIBILITY - THE VIEW FROM BEHIND THE WHEEL

- APPLICABILITY: Influence of rainfall and visibility on driver behavior
- DOCUMENT AUTHOR(S), SOURCE, DATE: Ivey, D.L., Lehtipuu, E.K., Button, J.W. Journal of Safety Research December 1975
- DOCUMENT IDENTIFICATION NO. None

The factors influencing wet weather accidents are complex, a fact sometimes ignored during the current popularity of blaming low tire pavement friction for most wet weather accident problems. A factor of significance is visibility, as influenced not only by rainfall intensity but to a great extent by traffic speed. This article presents a number of direct visibility observations and develops a framework useful in interpreting these data to determine the influence of reduced visibility on the operation of motor vehicles. Information from the literature shows the low probability of high intensity rainfalls. Conclusions concerning the hazard of passing maneuvers during rainfall of one inch (2.54 cm) per hour or more, and the need to reduce speed under wet weather conditions, are also presented.

b. II4B - THE USE OF RAINFALL CHARACTERISTICS IN DEVELOPING METHODS FOR REDUCING WET WEATHER ACCIDENTS IN TEXAS

- APPLICABILITY: Percent of Time of Wet Pavement, Wet Weather Accident Rates, Skid Resistance, Pavement Surface Water Depth, Design Rainfall Intensity
- DOCUMENT AUTHOR(S), SOURCE, DATE: Hankins, K.D.
  Texas State Department of Highways and Public Transportation
  Interim Report, August 69 - July 75
- DOCUMENT IDENTIFICATION NO. Report No. 135-4

This report was developed to provide a basis for further study of wet weather accidents. A method evolved to determine the percent of time the pavement is wet, leading to the development of a wet weather accident rate. A study of rainfall intensities was made. The average 85th percentile rainfall intensity of 18 weather stations was found to be 0.14 inches per hour (0.36 cm/hr), based on measurements of a one-hour duration. When extrapolated to a five minute duration, the 0.14 inch (0.36 cm) per hour intensity was found to be increased to 0.50 inch per hour (1.27 cm/hr). This intensity was termed the Average 85th Percentile Rainfall Intensity Based on a Five Minute Duration, and is suggested for use in design for skid resistance studies.

c. II4C - FIELD STUDY OF DRIVER VISUAL PERFORMANCE DURING RAINFALL

- APPLICABILITY: Visibility, Driver Performance, Rain
- DOCUMENT AUTHOR(S), SOURCE, DATE: Morris, R.S.; Mounce, J.M.; Button, J.W.; Walton, N.E.
  Texas Transportation Institute
  Sponsored by National Highway Traffic Safety Administration

- DOCUMENT IDENTIFICATION NO. None

The research investigated the affect of rain on visibility. Specifically, the degradation of static visual acuity in terms of visual angle, detection probability, and legibility as a function of rain intensity were determined. Experiments performed during the research included a field study during actual rain conditions, a simulator study using artificially produced rain, a film study using photographic techniques for the determination of visual degradation during simulated rain, and a freeway surveillance study to investigate driver behavior.

Significant findings of these studies include: a) water on the windshield is the primary factor accounting for reduced visibility, b) visual degradation (day) with windshield wipers operating seems to be a linear function of rain rate with normally encountered drop sizes, c) during night conditions, drop size is a significant factor in reducing visibility (smaller drops being a more serious problem than rain rate), d) the passenger side wiper has a severe obscuring effect on driver side viewing area at high rain rates, d) wiper speeds above 45 rpm* did not improve visibility (probably due to paragraph d), f) without windshield wipers visibility is reduced to unacceptable levels for driving (equivalent to greater than 20/200) in less than one second at rain rates greater than one inch (2.54 cm) per hour effective, g) since water on the windshield is the most significant factor in visual degradation, effective rain rate can be determined from vehicle velocity, drop terminal velocity, windshield rake angle, and actual rain rate.

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*Revolutions per minute

Section A3

MOTORIST GUIDANCE TECHNIQUES AND COUNTERMEASURES

A3-1 INTRODUCTION

The motorist guidance techniques and countermeasures which have been employed to deal with a reduced visibility environment are discussed in this section.

A3-2 GENERAL

Miscellaneous topics are discussed in this paragraph.

a. III2A - ADVERSE WEATHER, REDUCED VISIBILITY AND ROAD SAFETY

• APPLICABILITY:	Problems associated with driving under reduced visibility conditions (fog, rain, snow, smoke and dust), human factors engineering, adverse weather control techniques, guidance clues and traffic control, function requirements of remedial measures, evaluation of countermeasures
• DOCUMENT AUTHOR(S), SOURCE, DATE:	OECD Road Research Group Study Report, August 1976
• DOCUMENT IDENTIFICATION NO.	None

The Road Research Group on Driving in Reduced Visibility Conditions due to Adverse Weather was established to examine the problems of driving in reduced visibility conditions, to determine the magnitude of the problems relative to traffic safety, and to study countermeasures. The group's report reviews the available data regarding accident frequency under reduced visibility due to fog, snow, dust, and smoke; and meteorological information concerning the frequency of these conditions. Consideration was also given to indirect causes of reduced visibility (e.g., splash and spray), and also the influence these factors may have on the decision-making process of the driver.

The report also deals with the various available countermeasures which can be directed toward lessening the risk of driving in adverse weather, including those aimed at reduction and/or removal of the source of reduced visibility, and those methods and techniques designed to warn and guide drivers confronted with reduced visibility conditions. A methodological approach to the evaluation of the effectiveness of countermeasures is presented, and particular attention is given to cost-effectiveness studies.

b. III2B - WORKSHOP ON HIGHWAY VISIBILITY

- APPLICABILITY: Highway visibility, vehicular lighting systems, driver in a restricted visibility environment, fixed roadway lighting
- DOCUMENT AUTHOR(S), DOURCE, DATE: Committee on Visibility, Highway Research Board Report, July 18-20, 1972
- DOCUMENT IDENTIFICATION NO. None

This report is a collection of papers presented by the members of the Committee on Visibility. The papers contained in this report are as follows:

- Title: Visual Tests for Driver Licensing
  Authors: Henderson, R.L. and Burg, A., 23 pages
- Title: Vehicular Lighting Systems for Two-Lane Rural Highways
  Author: Meese, G.E., 16 pages
- Title: A Review of Visibility Factors in Roadway Signing
  Author: Woltman, H.L., 23 pages
- Title: Illuminance Versus Luminance
  Author: King, L.E., 14 pages
- Title: Minimizing the Hazard of Restricted Visibility In Fog
  Author: Schwab, R.N., 11 pages
- Title: State-of-the-Art in Warrants for Fixed Roadway Lighting
  Author: Rowan, H.J., 36 pages.

c. III2C - MATHEMATICAL EVALUATION FOR CONTROLLING HAZARDS

- APPLICABILITY: Risk analysis for hazardous situations, cost and effectiveness of remedial measures
- DOCUMENT AUTHOR(S), SOURCE, DATE: Fine, W.T.
  Journal of Safety Research
  Vol. 3, No. 4., p. 157-166, Dec. 1971
- DOCUMENT IDENTIFICATION NO. None

To facilitate efficient control of hazards for accident prevention, two significant needs have been recognized. One is the need for a method to determine the relative seriousness of all hazards for guidance in assigning priorities to preventive effort. The second need is for a method to measure the justification of the estimated cost of the contemplated corrective action.

To fulfill these needs, the author gives a formula that "calculates" the risk of a hazardous situation and gives a numerical evaluation to the urgency for remedial attention to the hazard. Calculated risk scores are then used to establish priorities for corrective effort. An additional formula weights the estimated cost and effectiveness of any contemplated corrective action and gives a quantitative estimate of the justification of the cost.

d. III2D - COMMUNICATION HANDBOOK FOR HIGHWAY DEPARTMENTS

• APPLICABILITY:	Development of a handbook for use by highway agencies, communications handbook
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Hutt, S.Z. Illinois Department of Transportation Division of Highways Highway Research Record, Number 402
• DOCUMENT IDENTIFICATION NO.	None

This paper describes the application of a communications handbook to the Illinois Division of Highways. The purpose of this program was to augment the procedure model and data program in order to validate such a system and facilitate long-range communication planning by highway departments. The handbook procedure was to be followed as closely as possible. Any changes or improvements found were to be recorded separately and initiated to test their practicability. The highway department is a formal organization. The procedure for gathering information exchange followed a function-and-activities pattern. The committee developed a method of gathering the communication exchange, relative to each function and activity by the use of preprinted forms. Information was compiled for use with a design data program. The revised handbook contains a step-by-step procedure for conducting a communications requirements study and for designing a communications system.

e. III2E - POSITIVE GUIDANCE IN TRAFFIC CONTROL

- APPLICABILITY: Positive guidance in relation to the driving task, motorist information, hazards, information handling, procedure for applying positive guidance
- DOCUMENT AUTHOR(S), SOURCE, DATE: Alexander, G.J., Lunerfeld, H. Federal Highway Administration Office of Traffic Operations Pamphlet, April 1975
- DOCUMENT IDENTIFICATION NO. None

Positive guidance is an approach designed to provide high payoff, short-range solutions to safety and operational problems at relatively low cost. It is based on the premise that a driver can be given sufficient information to avoid accidents at hazardous locations. In this pamphlet, positive guidance has been set into a system analysis methodology. A procedure has been developed consisting of six major functions. The first three functions are data collection at problem locations, specifications of problems, and definition of driver performance factors. These serve as analytical and diagnostic tools to determine the location and nature of safety and operational problems. The next two are definition of information requirements and determination of positive guidance information. These aid in the design of remedial information system corrections. Finally, evaluation provides the means to determine the effectiveness of the solutions.

f. III2F - SELECTION OF TRAFFIC CONTROLS FOR SEVERE WEATHER CONDITIONS

- APPLICABILITY: Quantification of hazard due to reduced visibility
- DOCUMENT AUTHOR(S), SOURCE, DATE: Rourke, R.J., Bode, J.J., Jeya, P. Arthur Young and Company, March 1977
- DOCUMENT IDENTIFICATION NO. FHWA-RD-77-70

This manual provides guidelines for the selection of traffic controls to reduce the hazards created by severe weather conditions to travel on limited-access highways. The guidelines emphasize the need to determine the severity of the hazard and to estimate the level of investment that is warranted prior to implementation of a control to counter the hazard. The criteria to be applied to ensure that the basic functions of traffic control are achieved are provided as an aid in the selection or design of traffic control measures. Analytical techniques are described in procedural format, along with worksheets, for use by traffic engineers in quantifying the extent of the accident or delay hazard created by extreme weather conditions. A methodology for selection of the most appropriate traffic control is presented based on estimating the level of effectiveness that must be achieved by a control in order to be cost effective.

Summary descriptions of traffic controls implemented by the States under various adverse weather conditions, and a comprehensive annotated bibliography are provided in appendices to the report.

A3-3 FOG

Improving driving conditions in fog are discussed in this paragraph.

a. III3A - FOG: A REVIEW OF THE LITERATURE PERTAINING TO HIGHWAY PROBLEMS AND POSSIBLE SOLUTIONS

- APPLICABILITY: Literature Review
- DOCUMENT AUTHOR(S), SOURCE, DATE: Marion F. Creech
  Virginia Highway Research Council, July 1972
- DOCUMENT IDENTIFICATION NO. VHRC 72-R2

Problems associated with driving in a reduced visibility environment, fog abatement, and visual guidance systems are reviewed in this report. Promising methods for improving visibility are outlined.

A brief summary of the major findings of this study are presented below:

- Systems that adequately abate fogs or lighting systems that provide minimum visibility requirements have not evolved.
- Most abatement techniques stem directly from methods used at airports. It is well to use methods already developed, but the roadway requirements are different from runway requirements.
- It is very probable that a lighting system can be designed that will produce a visibility level equal to the before-fog conditions.
- Manufacturers of lighting equipment are interested in mass producing their products, however, they have done little research in the area of fog lighting. Consequently, any lighting system developed for motorist guidance through fog would have to be designed by the highway organization requiring it with very little guidance from the manufacturers.
- Fog abatement techniques have not progressed to the point that they are feasible for highway usage.
- A combination low level lighting system and lineal guidance system will improve visibility and enhance driver control.

b. III3B - REDUCED VISIBILITY (FOG) STUDY

- APPLICABILITY: Test and evaluation of countermeasures aimed at reducing the fog accident potential. Roadway guidance techniques, enforcement, public information and intervehicle communications
- DOCUMENT AUTHOR(S), SOURCE, DATE: California State Division of Highway, Sacramento
  Traffic Dept. Report, March 1967
  132 pp
- DOCUMENT IDENTIFICATION NO. STS-738

This report summarizes research conducted by the California Transportation Agency to find or develop various means of giving advance warning to motorists of the need for greater alertness and caution when driving in reduced visibility conditions. The purpose of the study was to find means of preventing, insofar as possible, the multiple vehicle accidents associated with reduced visibility. The methods in dealing with the fog accident problem were classified into four general categories: Roadway Techniques (variable speed signing, edgeline striping, color striping at ramps, raised lane line striping and audio signs), Enforcement (patrol activity), Public Information, and Intervehicle Communications. All of these techniques were tested on the highway at various study sites. The study results indicated that only the posted speed limits (on variable message signs) had any measurable effect on traffic. This effect was limited and occurred primarily when traffic volumes were under 1,000 vehicles per hour. The effect was more pronounced on expressways than on freeways. Research on vehicle rear-end lighting indicated by this study is continuing.

c. III3C - HIGHWAY FOG PROJECT

- APPLICABILITY: Literature review and state-of-the-art summary of fog, effects of fog on driving, traffic measurements in fog, data collection system, fog abatement techniques, vehicle guidance techniques, experimental design
- DOCUMENT AUTHOR(S), SOURCE, DATE: Kocmond, W.C. and Perchonok, K., Cornell Aeronautical Laboratory, Inc. Prepared for the Highway Research Board, NCHRP Report No. 95, 1970
- DOCUMENT IDENTIFICATION NO. Contract No. HR-56

A literature review conducted during the study showed that fog had the following effects: a slight reduction in the accident frequency; an increase in the likelihood that an accident will result in a fatality; and an increase in the likelihood that accidents will involve either a single vehicle or more than three vehicles. Traffic measurements made during the study indicated that: vehicle speeds were slightly lower in fog; the probability of overdriving one's visual range is greatly increased; and lateral location and vehicle interactions were not affected by fog. It was concluded that drivers exercise more caution in fog, but that the increase in overdriving probably explains the increased severity of accidents.

Fog abatement methods are discussed, including seeding with hygroscopic material, vegetation barriers, use of helicopters to mix the air, and inhibition of evaporation from water reservoirs. A vehicle guidance system involving the use of polarized headlamps was evaluated in field experiments and judged impractical as an aid to drivers in fog. Measurements of the effect of vehicle lighting on visibility showed that rear lighting system can be improved to allow better detection of vehicles in fog.

d. III3D - SPECIAL STUDY - REDUCED VISIBILITY (FOG) ACCIDENTS ON LIMITED ACCESS HIGHWAYS

- APPLICABILITY: Highway fog visibility problems, driver education, fog detection and guidance systems, fog abatement techniques, police-highway department procedures, vehicle lighting, postaccident control of accidents, cost effectiveness, crash injury reductions, improved braking of vehicles, enforcement of basic speed rule in fog
- DOCUMENT AUTHOR(S), SOURCE, DATE: National Transportation Safety Board Bureau of Surface Transportation Safety Special Study, November 15, 1972
- DOCUMENT IDENTIFICATION NO. NTSB-HSS-72-4

The National Transportation Safety Board undertook detailed investigations of several highway accidents in which the presence of fog was a contributing factor. At the time that this report was written, these included the Motor Carrier Highway accident near Joliet, Illinois on August 12, 1967, the Interstate Bus-Automobile Collision on Route 57 near Petersburg, Indiana on November 24, 1969, and the Multiple Vehicle Collision on the New Jersey Turnpike on November 29, 1969.(1)

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[1]Subsequent to the date this report was issued, the NTSB also conducted detailed studies of the multiple vehicle collision on the New Jersey Turnpike in October 1973, and in Corona, California, February 1975

This study is the culmination of what the Safety Board learned through its accident investigations, public hearings, fog symposia, and reviews of pertinent literature. It reviews the various approaches which have been taken to prevent fog accidents; e.g. Driver Education, Fog Guidance Systems, Environmental Control.

The study also provides recommendations intended to alleviate the problem from several directions; namely, driver education, police-highway department procedures for closing highways, enforcement of the basic speed rule as related to fog accidents, mutual-assistance pacts for postaccident control of accidents, implementation of Highway Safety Programs Standards and Federal Highway Administration plans to develop highway guidance systems.

e. III3E - MOTORIST ADVISORY SYSTEM FOR FOG AND ICE CONDITIONS: FEASIBILITY STUDY

- APPLICABILITY: Literature review on fog warning systems, user survey of fog detection equipment, review of other sensor/monitoring equipment, review of sign types used for providing fog warning messages, survey of guidance equipment and other motorist aids, central data processing equipment, development of logic for control system signs, benefit/cost analysis

- DOCUMENT AUTHOR(S), SOURCE, DATE: Illinois Department of Transportation
  Prepared by: Sperry Rand Corporation, Sperry Systems Management
  October 1975

- DOCUMENT IDENTIFICATION NO. None

This report describes the work accomplished in investigating the feasibility of a fog and ice detection and warning system for a ten-mile (16.1 km) section of Interstate 55 southwest of Joliet, Illinois which is frequently prone to fog development. The tasks performed during this study included:

- Data Collection. To obtain accident, weather, and other pertinent data for use in determining sensor and signing locations, and to estimate costs of accidents. A literature survey on fog and ice systems was also included.

- Fog and Ice Sensor Surveys. To obtain information from user agencies for assessing the suitability of presently available equipment.

- Other Sensor/Monitoring Equipment Review. To determine the applicability of other devices such as closed circuit television and vehicle detectors for the system.

- Signing Configuration. To determine the type and location of fixed and variable message motorist warning signs to satisfy both fog and ice warning requirements.

- Guidance Equipment and Other Motorist Aids. To examine the application of various techniques such as strobe lights, "pancake" lights, and other delineation techniques for improving system effectiveness.

- Data Processing Configuration. To determine the equipment required to process the data from the field sensors and control the warning signs.

- Communications Configuration. To establish the type of communications technique and transmission medium for field-to-central and central-to-field interconnections.

- Electrical Power. To determine the amount of power required for all system elements, the availability of power in the study area, and the power drop configuration.

- Control Concept Development. To develop the basic logic for analyzing the data from the various sensors and generating the control commands for sign activation under various operational conditions.

- Proposed System Configuration. To bring together the results of the study into a configuration which can satisfy the objectives of the system.

- Benefit/Cost Analysis. To assess both the cost of system implementation and operation, and the expected benefits for development of a system benefit/cost ratio.

The final output of the feasibility study was a proposed operational system, based on commercially available equipment. The criteria used in the evaluation and selection of equipment types included: performance, reliability, maintainability, user convenience and cost. Briefly, the proposed system included the following elements: fog and ice sensors, vehicle sensors, fixed and variable message signs, communications and central data processing equipment. The basic function of the system is to warn the motorist by providing him with the appropriate advisory information so that he may adjust his speed to a safer level before encountering dense fog patches or bridge ice. The results of a benefit/cost analysis for the proposed system were favorable, leading to a recommendation that the system be considered for implementation.

f. III3F - DEVELOPMENT OF A FOG DETECTION SYSTEM

- APPLICABILITY: Traffic in fog, vehicle guidance systems, warning signs
- DOCUMENT AUTHOR(S), SOURCE, DATE: Wright, W.R.
  Ohio Department of Transportation
  Proceedings of the 29th Annual Ohio Engineering Conference
  Vol. 29, April 1975: pp 168-177
- DOCUMENT IDENTIFICATION NO. None

The results of the study on the effects of fog related to traffic are listed, vehicle guidance under low visibility conditions are described, the results of a study of fog frequency are summarized, and the provision of advance motorist information is discussed. Current and future sign control systems are briefly reviewed. Studies have shown that the probability of overdriving increases sharply as the visual distance decreases. Active, passive and signaling visual guidance systems are outlined. Fog frequency data reveals that dense fog occurs on more than 20 days a year in over 60 percent of the areas covered by Weather Bureau Stations. The "flip-type" fog warning sign with flasher and its operation are described. The erection of a series of signs approaching the fog area, edgelines and raised pavement markers for better guidance, and electronic fog detectors including the Transmissometer are described.

g. III3G - HIGHWAY FOG

- APPLICABILITY: Highway fog analysis, visibility measurements and model verification, highway fog countermeasures, warning and guidance systems, analytic model development and fog model parameters on road test operations, and instrumentation, safe stopping speed study, driving simulator study, fog measurement techniques, highway fog countermeasures summary, performance degradation caused by visual search
- DOCUMENT AUTHOR(S), SOURCE, DATE: Heiss, W.H.
  Sperry Rand Corporation
  Sperry Systems Management
  Prepared for: Highway Research Board, NCHRP
  Final Report, December 1972
- DOCUMENT IDENTIFICATION NO. NCHRP 171

This report describes the analytic study of highway fog that was undertaken to determine the fog densities that produce significant detrimental effects on highway safety and traffic operations. The study also evaluated the feasibility of a number of active and passive warning and guidance systems to improve safety and efficiency of traffic flow through the areas.

A fog visibility index was developed as a means of quantifying fog levels. Three analytic models of visibility through fog, based on the detection of a stopped vehicle in a through lane of a freeway under different lighting conditions, were the basis for the development of the index. The fog visibility index, for which "instrument" visibility (or extinction coefficient) and ambient light level were inputs, was calibrated and validated by computer simulation studies and a series of on-road tests in fog.

The analysis, as corroborated by the on-road tests in fog, showed that although the driver is deprived of some useful visual information at less dense fog levels, driver performance is not seriously degraded until the visibility drops below about 600 feet (180 m) in daylight.

Limited tests on the UCLA closed circuit television driving simulator demonstrated successful simulation of fog. Based on limited data, the driving simulator tests indicate that the reaction and perception time of a reasonably alert driver in fog is about 1.4 seconds, which is less than the time normally used for sighting distance calculation.

A survey was made of available fog measuring instrumentation. The scatter type instruments appear to be the most suitable for general highway fog use, although they are not as accurate as transmissometers. All of the instruments currently available measure a more or less limited sample of fog, and therefore single-device installations are subject to gross errors in patchy fog and bank fog.

Tests under realistic highway conditions in the presence of dense fog constituted perhaps the most difficult task of this project. A significant number of runs was made possible through the use of weather prediction advisors, the availability of an instrumented test vehicle, and the cooperation of willing test subjects.

Some potentially useful fog countermeasure techniques are available to the highway designer and traffic engineer. In the near term, variable message signs can be effective when properly used. Lane marking "pancake" lights have potential as guidance aids to help keep drivers from becoming disoriented, particularly when unexpectedly entering a dense fog area.

Some of the more advanced active guidance systems appear to be technically feasible, and the simpler block guidance systems are technically feasible at the present time. Such systems may be economically feasible in conjunction with freeway surveillance and control system installation. In the longer term, passing aids and automatic guidance systems currently being studied may prove to be readily adaptable to guidance systems for highway fog.

h. III3H - HOW ROAD TRAFFIC IN GREAT BRITAIN COPES WITH FOG

- APPLICABILITY: Nighttime fog, measurements of sight distance, fog lamp usage with on the road observations, polarized light, daytime fog
- DOCUMENT AUTHOR(S), SOURCE, DATE: Jehu, V.J. Reprint from Zeitschrift fur Verkehrssicherheit Vol. 9, No. 3/4-1963, pp. 284-290
- DOCUMENT IDENTIFICATION NO. None

Recommendations regarding vehicle lighting practices are made which should help to keep traffic moving in fog. At night the fogbeam should be a wide spread of light immediately ahead of the vehicle, preferably from two lamps; if only one fog-lamp is used it should be mounted on the right hand side of the vehicle (for left hand traffic) to make the best use of the reflecting road studs in the lane markings along the road, and to define the vulnerable outside wing of the vehicle to oncoming drivers. By day the headlights should be switched to either the upper or lower beam to warn other road users of the vehicle's approach. Overtaking another vehicle in daytime fog should not be attempted without adopting this precaution.

These procedures are no more than recommendations in Britain, there being no legal requirement that they should be adhered to.

i. III3I - DESIGN OF ADVERSE WEATHER AND VISIBILITY HAZARD WARNING SYSTEMS

- APPLICABILITY: Adverse weather and traffic operations, system concepts and functional components, alernative remedial systems, criteria for testing systems, development of systems designs, recommended configuration for an adverse weather and visibility hazard warning system
- DOCUMENT AUTHOR(S), SOURCE, DATE: Office of Traffic Operations Federal Highway Administration Report, September 1972
- DOCUMENT IDENTIFICATION NO. None

Fog is a highway visibility problem to a hazardous extent in at least 60 percent of the United States. Reduced visibility from snow, blowing sand, and rain constitutes a similar problem in particular geographical areas. The burden to alleviate this problem rests with the States and other authorities operating the highway system.

This report reviews existing fog warning and detection systems and provides overall guidance for attacking the fog problem. The following basic functional components for a system are described: Operational logic, detection, communications, control and surveillance, and display. The pivotal act of the guidance function is the traffic engineering judgment as to what vehicle control should be exercised by drivers to optimize traffic flow under the given environmental conditions. Technical design capability and reliable hardware are readily available for application to new traffic operations control systems. This report describes the criteria for testing alternative control system designs. Six performance requirements - technical capability, reliability, ease of implementation, cost, enforceability, and motorist acceptance are used to define the characteristics of the desired operational system. A typical fog problem situation is described accompanied by a recommended configuration for an adverse weather and visibility hazard warning system.

j. III3J - FOG ACCIDENT PREVENTION STUDY: VISIBILITY OF COLORED LUMINOUS AREAS IN FOG

• APPLICABILITY:	Visibility of colored luminous areas, experimental test procedures
• DOCUMENT AUTHOR(S), SOURCE, DATE:	California University, Berkeley Vehicle Technology Facility Final Report, April 1969
• DOCUMENT IDENTIFICATION NO.	None

A series of subjective visibility tests, performed with luminous-area, red-light sources of different sizes in artificially generated fog, show that in daytime fog of 50-ft (15.2 m) visual range and nighttime fog of 100-ft (30.4 m) visual range, there was appreciable difference in visibility between 2-in. (5.08 cm) diameter and 6-in. (15.24 cm) diameter sources of equal intensities in nighttime fog of 500-ft (152.4 m) visual range, the larger source was found to be somewhat more visible than the smaller one. Another series of subjective tests were performed under various visibility conditions to determine the visual detection contrasts for red, amber and green luminous area targets viewed against correspondingly colored backgrounds. The results show that under clear weather conditions daytime or nighttime, there was an appreciable difference in target-to-background detection contrast for the three colors. In fog of 100 to 150 feet (30.5 - 45.7 m) visual range, however, the detection contrast was generally lower, for the red targets than for the green with that for amber being intermediate between the other two colors. These differences were more pronounced in day-time fog than in nighttime fog of the same density.

k. III3K - DRIVING IN FOG ON THE M4

- APPLICABILITY: Driver answers on fog questionnaire compared with results of statistical analysis of their observed driving behavior
- DOCUMENT AUTHOR(S), SOURCE, DATE: R. Sumner, C. Baguley, and J. Burton Transport and Road Research Laboratory, Crowthorne, England, 1977
- DOCUMENT IDENTIFICATION NO. TRRL Supplementary Report No. 281

The report describes an experiment made on 1,780 vehicles driving in fog on the M4 freeway in Great Britain. The purpose of the experiment was to correlate visibility conditions and advisory speed signs to speed reductions. Vehicles were photographed by an Orbis III system whenever the visibility, as measured by a fog detector, dropped to 656.2 feet (200 meters) or less. Simultaneously recorded were vehicle speed, registration number, day, time, lane, and visibility level. The tests were made between 3 November 1975 and 31 March 1976.

The registered owners of 600 of the 1,780 vehicles were traced and sent a questionnaire asking for the driver's opinion on the condition in which the vehicle was photographed and on driving in fog generally. Seventy-six percent of the questionnaires were returned.

At a visibility of 164 feet (50 meters) or less, more than half the drivers were exceeding the speed at which they could stop within the visibility distance. Daylight or darkness had no significant effect on vehicle speeds during periods of fog. Statistical analysis from the data indicates that advisory speed signs readings appear to contribute as much as visibility itself in affecting actual vehicle speeds. Together these two factors have the largest effect on speed. Thirty-eight respondents commented on the advisory speed signs; most of these criticized the lack of suitable speed limits and mentioned the need for the signs to be brought up-to-date more frequently.

l. III3L - LITERATURE REVIEW SUMMARY - VEHICLE BASED FOG COUNTERMEASURES - INTERIM CONTRACT BRIEFING

- APPLICABILITY: Fog countermeasures
- DOCUMENT AUTHOR(S), SOURCE, DATE: Koth, B.W., McCunney, W. Franklin Institute Research Laboratories, June 8, 1977
- DOCUMENT IDENTIFICATION NO. Department of Transportation, Contract DOT-HS-6-01499 National Highway Traffic Safety Administration

This report is intended to supplement the Task 1 Summary Report, Vehicle Based Fog Countermeasures: Literature Review. It presents an integration of relevant findings from the review with a discussion of methods used in the analytical assessment of vehicle fog lamp effectiveness in Task 2 of the research effort.

The basic objectives of the literature review were to:

- Identify design and performance attributes of current front and rear-mounted fog lamps
- Determine the visual requirements of motorists for safe driving in fog
- Identify quantitative descriptions of fog and its occurrence
- Determine behavioral effects of fog on drivers and traffic
- Determine the scope and nature of fog accidents.

Literature was identified using a Franklin Institute Research Laboratories Computerized search and retrieval procedure; relevant publications were then weeded and sorted manually. Information from nearly 300 literature items have been included in the review.

m. III3M - "CHANGEABLE MESSAGE" WARNING SIGNS IN DENSE FOG (INTERIM REPORT)

• APPLICABILITY:	Effect of warning signs on vehicle speed in fog
• DOCUMENT AUTHOR(S), SOURCE, DATE:	California Highway Patrol Analysis Section Caltrans Internal Report, December 1, 1976 - March 31, 1977
• DOCUMENT IDENTIFICATION NO.	None

The California Highway Patrol (CHP) and the Department of Transportation (Caltrans) cooperated in this Fog Sign Study to determine the usefulness of "changeable message" warning signs in dense fog. The study was conducted in the Stockton Area on SR 99 south of Stockton and in the Riverside Area on SR 91 near Corona.

Five warning signs with telescoping stand and strobe light were assigned to each area. Two cloth changeable messages were used: DENSE FOG AHEAD and WRECK AHEAD. These messages were attached to a basic sign by means of velcro fasteners and could be easily changed to meet operational needs. The signs were collapsible so they could fit in the trunk of the patrol car.

When there was an accident in light to heavy fog, the CHP patrol unit put up the warning sign with the message, WRECK AHEAD. To prevent potential chain reaction accidents, the other warning sign with the message DENSE FOG AHEAD was put up whenever there was a fog bank ahead of 200 feet (61 m) or less visibility.

The intent of the study was to determine what effect the warning signs had on vehicle speed. Also, the practicality and usefulness of the signs were to be determined through comments by CHP officers.

A3-4 DUST

No literature on driving in dust is available at this time.

A3-5 SNOW

Snow drifts and fences are discussed here.

a. III5A - STUDIES OF: (A) TRAFFIC CONTROL CRITERIA FOR WIND AND VISIBILITY, AND (B) CAPACITY OF THE NEW STANDARD-PLAN SNOW FENCE

• APPLICABILITY:	Visual range during blowing snow conditions, wind speed and accident frequency, characteristics of new standard-plan snow fences (capacity and drift configuration)
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Tabler, R.D. Rocky Mountain Forest and Range Experiment Station Colorado State University Sponsored by the Wyoming State Highway Department Final Report, September 1973
• DOCUMENT IDENTIFICATION NO.	None

This report is composed of three Wyoming based studies: Visibility Study - to develop visual range criteria for traffic control during blowing snow conditions; Wind Study - to determine the relationship between wind speed and accident frequency; and characteristics of the drifts behind the new standard-plan fences at saturation to determine the capacity and drift configuration of the new fences being used. The following methods were employed, respectively: (1) for all drifting events, averages and minimum visual range were determined over all ten-minute intervals having a minimum visual range greater than an average visual range 1,200 feet (365.8 m); (2) wind related accidents from 1 October 1971 through 1 April 1973 were reviewed for concurrent average wind speed and range for the hour of the accidents to derive a frequency distribution; a relationship was determined between the average wind speed and the maximum gust, and then these values were determined for the first ten minutes of each hour, over an eight hour period centered about accident time; (3) snow depths were measured behind all saturated fences. The conclusions were: traffic control regulations should be put into effect for average wind speeds greater

than approximately 30 mph (48.3 km/hr); visibility recommendations must be considered tentative; there is reason to believe that the exceptional snow depths and capacity behind the new fences are due to the 15-degree inclination to leeward, in combination with the horizontal slats.

b. III5B - A BRIEF REVIEW OF SNOWDRIFTING RESEARCH

- APPLICABILITY: Blowing snow phenomenon, practical procedures for controlling windblown snow, wind tunnel studies modeling criteria for snowdrift simulation, suggestions for future research
- DOCUMENT AUTHOR(S), SOURCE, DATE: Mellor, M.
  Paper presented at the International Symposium on Snow Removal and Ice Control Research
  April 8-10, 1970
  Highway Research Board, Special Report 115
- DOCUMENT IDENTIFICATION NO. None

The blowing-snow phenomenon is described, and practical procedures for controlling deposition of windblown snow are reviewed. Field methods are given for measuring velocity, particle concentration, mass flux, particle size, and their distributions with respect to height. The analysis of steady-state wind transport over a plane surface is outlined, and difficulties in extending the treatment to cover complex flow perturbations are stressed. Wind tunnel studies are reviewed, and modeling criteria for snowdrift simulation are given. Suggestions for future work include semi-empirical model and prototype studies for short-term benefits, and extension of fundamental analyses and field observations for progress over the long term.

c. III5C - AERODYNAMIC SNOW FENCES TO CONTROL SNOW-DRIFTING ON ROADS

- APPLICABILITY: Snow drift control, geomorphological-climatic factors and snow fences, aerodynamic snow mechanics aspects of snow fences, spacing of snow fences, suggestions for additional studies to improve effectiveness of snow fences

- DOCUMENT AUTHOR(S), SOURCE, DATE: Jumikis, A.R. Paper presented at the International Symposium on Snow Removal and Ice Control Research April 8-10, 1970 Highway Research Board, Special Report 115

- DOCUMENT IDENTIFICATION NO. None

This paper describes some problems of snowdrifting control on roads in open terrain. Some of the relationships between geomorphological-climatic factors and snow fences as snowdrifting control devices are discussed. The aerodynamic-snow mechanics aspects of snow fences and flow processes of air-snow currents across dense and permeable snow fences are described, rough calculations are made for spacing of snow fences, and difficulties in theoretical analyses of aerodynamic snow fences are discussed. The paper also suggests additional studies that are needed to improve the effectiveness of snow fences. These include studies of geomorphology and climate of regions prone to snowdrifting, aerodynamics of snowdrifting, and aerodynamic-snow mechanics of various kinds of snow fences and their components.

d. III5D - LOCATING SNOW FENCES IN MOUNTAINOUS TERRAIN

- APPLICABILITY: Test results of large snow fences, cross section profiles of resulting snowdrifts, locating snow fences in mountainous terrain

- DOCUMENT AUTHOR(S), SOURCE, DATE: Schmidt, R.A. Paper presented at the International Symposium on Snow Removal and Ice Control Research April 8-10, 1970 Highway Research Board, Special Report 115

- DOCUMENT IDENTIFICATION NO. None

A series of tests with large snow fences to control snow accumulation in alpine areas of central Colorado has provided greater understanding of the effects of surrounding terrain on snowdrift control with fences. Cross-sectional profiles of the resulting snowdrifts show that an upslope approach to the fence causes a short, high drift to form compared to the long shallow drift formed with a downslope approach. In the downslope approach, however, the total volume of snow trapped by the fence may equal or exceed the volume in the drift behind a fence with an upslope approach. Problems of locating fences for maximum effectiveness in irregular terrain are complicated by the need to maintain a gap between the fence and ground throughout the snow season. Placing fences in the lee of a ridge crest or other natural terrain break often increases the adverse pressure gradient and results in snow deposition upwind of the fence. Some criteria for avoiding this situation are presented.

A3-6 DELINEATION TREATMENTS

Roadway markings and their effectiveness are discussed here.[1]

a. III6A - OPTIMIZATION OF TRAFFIC LANE DELINEATION SYSTEMS

- APPLICABILITY: Raised pavement markers, glass beads, thermoplastic, delineation, traffic stripe, traffic paint
- DOCUMENT AUTHOR(S), SOURCE, DATE: Miller, Tom
  Office of Traffic
  California Dept. of Transportation
  Final Report, December 1976
- DOCUMENT IDENTIFICATION NO. FHWA-TS-77-200

This report summarizes the results of an investigation of the initial costs, maintenance costs, application methods, and physical properties of three systems of pavement delineation (paint, raised pavement markers, and hot spray thermoplastic) on different types of highways.

The results show that the number of non-reflective pavement markers on freeways may be reduced 50 percent from existing standards. This reduction will provide good delineation for the motorist at a considerable savings in cost. The quantity of paint and glass beads necessary for lane lines, edgelines and center lines may be reduced 33 percent from existing standards, at a considerable saving in cost. The use of hot spray thermoplastic is not recommended since its cost for striping is about 3.5 times more than a painted stripe. The lasting qualities have not yet been determined. Existing experimental locations will show this at a later date.

Additional savings will be realized from maintaining the proposed delineation patterns because fewer markings, paint and glass beads are required and because of improved marker design, placement and computerized paint schedule.

b. III6B - FIELD EVALUATION OF SELECTED DELINEATION TREATMENTS ON TWO-LANE RURAL HIGHWAYS

- APPLICABILITY: Rural delineation, novel delineation treatments, accidents, traffic performance measures, speed, lateral placement

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[1]For data on delineation requirements from the drivers point of view, see also DRIVER'S VISIBILITY REQUIREMENTS FOR ROADWAY DELINEATION, Allen, R.W. et al; FHWA-RD-77-165 and FHWA-RD-77-166.

- DOCUMENT AUTHOR(S), SOURCE, DATE: Stimpson, W.A.; McGee, H.W.; Kittelson, W.K.; and Ruddy, R.H.; Alan M. Voorhees and Associates, Inc. Sponsored by: Office of Research and Development, Federal Highway Administration Final Report, October, 1977

- DOCUMENT IDENTIFICATION NO. FHWA-RD-77-118

The first objective of the Phase I research was to establish the relationships between various traffic performance measures and accident probability of two-lane rural roads. Accident data and speed and lateral placement measurements were collected for typical roadway sections of both tangent and curvilinear alignment. Multiple linear regression analysis was then used to develop an accident prediction model. Important influencing variables were centrality of vehicle placement within the lane, difference in lateral placement variance along the roadway section, skewness of the speed distribution, pavement width, and shoulder width.

The second objective was to incorporate the model in an overall methodology which would permit the efficient field evaluation of new or novel delineation treatments without having to collect before-and-after data over a multi-year time period. The methodology was tested in Phase II by applying it to a series of potentially more cost-effective treatments identified in earlier surveys.

c. III6C - ROADWAY DELINEATION SYSTEMS

- APPLICABILITY: State-of-the-art summary, guidelines for decision making, delineation situations and evaluation, delineation applications, human factors, cost-benefit analysis, delineation treatments, accident analysis

- DOCUMENT AUTHOR(S), SOURCE, DATE: Pennsylvania State University and Institute for Research Prepared for Highway Research Board NCHRP Report No. 130, 1972

- DOCUMENT IDENTIFICATION NO. None

Roadway delineation treatments and systems are installed to aid drivers in controlling their vehicles, thereby improving highway safety and easing the driving task. A logical process was used when installation decisions have been made. The information developed in this research report provides a meaningful and usable means to strengthen the decision process and enhance the likelihood of cost effective solutions.

As part of the research study, a comprehensive state-of-the-art summary covering the application of various delineation treatments to highway situations, delineation material properties, the human factors literature pertinent to delineation, and cost effectiveness consideration was compiled. Also, specific driver performance requirements at eight "classical" geometric situations are defined.

The experimental research consisted of laboratory and field studies. The studies included the use of post delineators and/or raised pavement markers at horizontal curves, the use of colored pavements, variations in center line marking patterns, and variations in color and spacing of post delineators at stop approaches.

Recommendations for the application of the various treatments at each of the "classical" stiuations are cited on the basis of the experimental studies, discussions with other researchers and practicing engineers, and a careful review of the literature. The report provides Guideline Forms to formalize and structure the decision making, ensuring considering of the important factors in their proper relationship.

d. III6D - DEVELOPMENT AND EVALUATION OF RAISED PAVEMENT MARKERS, 1971-1974

- APPLICABILITY: Traffic markings, reflective markers, reflector buttons, canes, snowplow markers, pavement markers
- DOCUMENT AUTHOR(S), SOURCE, DATE: Beede, B.K. and Shelley, T.L. Office of Transportation Laboratory California Department of Transportation Final Report, December 1975
- DOCUMENT IDENTIFICATION NO. CA-DOT-TL-5152-3-75-20

Evaluation and development of traffic delineators by the State of California is a continuing project. Six reflective and three combination reflective and nonreflective pavement markers were evaluated and are described in this report. None of the new raised reflective pavement markers submitted to the Laboratory for testing and evaluation have shown better performance than the current State adopted ceramic and retroflective cube corner markers.

One combination day/night ceramic marker which was tested is being recommended as an alternative to the presently specified system in median areas or on low volume roads.

e. III6E - DRIVER PERFORMANCE RELATED TO MEDIAN VISIBILITY

- APPLICABILITY: Median Visibility, Experimental Study Design
- DOCUMENT AUTHOR(S), SOURCE, DATE: Yu, J.C.
  Virginia Polytechnic Institute
  Accident Analysis and Prevention
  Vol. 1, No. 2, October 1969
- DOCUMENT IDENTIFICATION NO. None

This paper describes the research study undertaken to identify and evaluate changes, if any, in driver performance resulting from altered median visibility on a divided highway. A discussion of the study design and analysis of the collected field data is provided. The study results indicate that the median delineation treatment had no significant effect on vehicle speeds under the study condition. However, the delineated condition did have an effect on vehicle lateral placement.

f. III6F - ROAD MARKING AND DELINEATION

- APPLICABILITY: Horizontal road markings, raised pavement markers (studs) and lateral delineators, evaluation criteria, testing procedures, economic aspects, future research needs
- DOCUMENT AUTHOR(S), SOURCE, DATE: Organization for Economic Co-Operation and Development
  OECD Road Research Group
  February 1975
- DOCUMENT IDENTIFICATION NO. None

The report deals with horizontal road markings, raised pavement markers (studs) and lateral delineators, and evaluates their main characteristics. The desirable quality criteria, such as all-weather visibility, skid resistance, drying time and durability, are specified for various materials; for each of the criteria, a definition is given of the necessary tests, including accelerated laboratory tests and road tests. An assessment of the main economic aspects is made and the possibilities for the application of economic calculations are reviewed. Finally, present trends with regard to new developments and priority areas for future research are highlighted.

g. III6G - EVALUATION OF RAISED PAVEMENT MARKERS FOR ROADWAY DELINEATION DURING FOG

- APPLICABILITY: Evaluation of roadway delineation markers, snowplowable and non-snowplowable markers, field tests of marking effectiveness
- DOCUMENT AUTHOR(S), SOURCE, DATE: Shepard, F.D. Virginia Highway and Transportation Council October 1976
- DOCUMENT IDENTIFICATION NO. VHTRC-77-R21

Reduced visibility due to adverse weather conditions results in an inability of motorists to readily observe pavement markings, signs, and vehicles. The condition that presents the most serious restriction is fog, although rainfall during the night frequently creates serious visibility problems. Because of the ability of reflex reflective devices and materials to provide pavement and roadway delineation at relatively low costs, the feasibility of using them for roadway delineation and vehicle guidance during fog was investigated, with emphasis on the nighttime visibility characteristics. Also, consideration was given to various experimental methods of marker placement for roadway delineation and protecting the markers from snowplow damage.

Two types of corner-cube raised markers were placed along the highway edge line on 20-foot (6.1 m) centers. In one placement concept, snowplowable and non-snowplowable markers were placed on the pavement surface; in a second concept, the markers were recessed below the pavement surface in grooves. The marking systems were subjectively evaluated by observing the legibility properties during fog and noting the number of markers visible. Based on the observations, the raised pavement markers were thought to provide sufficient nighttime roadway delineation for vehicle guidance during light to medium density fogs. Although data were not available for dense fog, it is felt that adequate delineation would be provided for such fog conditions.

The method of grooving the pavement in the vicinity of the edge line for the purpose of recessing the markers to provide snowplowability was found to be feasible, providing adequate drainage is provided and a groove is placed in front of the marker. The length of the groove depends upon the reflectivity-distance requirements.

h. III6H - STATE-OF-THE-ART ON ROADWAY DELINEATION SYSTEMS

- APPLICABILITY: Delineation treatments, pavement markings, raised pavement markers, post delineators, colored pavements, rumble strips, delineation systems
- DOCUMENT AUTHOR(S), SOURCE, DATE: Bali, S.G.; McGee, H.W.; Taylor, J.I. Science Applications, Incorporated Sponsored by: Office of Research and Development Federal Highway Administration Final Report, May 1976
- DOCUMENT IDENTIFICATION NO. FHWA-RD-76-73

i. III6I - DELINEATION SITUATIONS AND DELINEATION TREATMENTS

Roadway delineation treatments and systems provide guidance, regulatory, or warning information to drivers under various highway situations. This state-of-the-art report on roadway delineation systems consititutes an update to the National Cooperative Highway Research Program Report 130. In the first part of the report, studies documented since the publication of NCHRP Report 130 are reviewed. This review is organized under two headings; Delineation Situations and Delineation Treatments. Under the former heading, studies relative to the application of different delineation treatments and systems for various highway situations are evaluated. The latter heading contains reviews of the studies from the standpoint of materials, cost, maintenance, durability and environmental effects. Recommendations subject to ongoing research on delineation applications under different highway situations are given in the second part. A partially annotated bibliography is also included.

A3-7 AUDIO SIGNING (ROADSIDE RADIO)

The following pages cover the use of radio in conveying road and visibility conditions to motorists.

a. III7A - STUDY AND DEVELOPMENT OF HIGHWAY ADVISORY INFORMATION RADIO

- APPLICABILITY: Highway communications, motorist advisory radio, roadside radio, traffic information systems, audio signing
- DOCUMENT AUTHOR(S), SOURCE, DATE: Anderson, R.A., and Robertson, R.G. Atlantic Research Corporation Prepared for Federal Highway Administration Final Report, December 1974
- DOCUMENT IDENTIFICATION NO. None

A complete Highway Advisory Information Radio (HAIR) system was developed for audibly conveying traffic advisory and emergency information to the motoring public using a low power, limited coverage roadside transmitter at dedicated frequencies of 530 kHz and 1.606 MHz. Types of information conveyed include emergency messages, warning tones indicating the approach of an emergency vehicle, advisory messages to alert motorists of anomalies ahead and alternate routes, and trip needs such as information pertaining to gas, food, and lodging services. A major objective of the program was the development of special automotive receivers permitting the motorist to automatically receive the traffic messages while listening to his favorite AM or FM broadcast station. The radio transmission system utilized audio tone codes to achieve control of the automatic receivers; however, the system also permitted message reception with over 90 percent of existing AM automobile radios. Surveys of commercial automotive AM receivers were made to determine tuning range limits and receiving sensitivities at 530 kHz and 1.606 MHz. It was found that the capability of automotive AM radios to receive out of band signals depends almost entirely on field strength and not on the limits of tuning range.

b. III7B - THE EFFECT OF AUDITORY AND VISUAL PRESENTATION OF NAVIGATIONAL MESSAGES ON MESSAGE RETENTION

- APPLICABILITY: Auditory Messages, Navigation, Units of Information, Alerting Signs, Visual Presentation, Auditory Presentation
- DOCUMENT AUTHOR(S), SOURCE, DATE: Gatling, F.P.
  Traffic Systems Division
  Office of Research and Development
  Federal Highway Administration
  Final Report, June 1976
- DOCUMENT IDENTIFICATION NO. FHWA RD-76-94

Navigational messages containing from two to seven units of information were presented to three groups of subjects. One group of subjects received the messages after they had seen an alerting sign and, in response to the sign, tuned the radio to a specified frequency to receive the message (manual group). A second group received the messages automatically and aurally (automatic group). The third group received the information visually. The manual group did consistently poorer on message retention than the other two groups. There was no difference in message retention between the aural automatic group and the visual group.

c. III7C - AUDITORY MESSAGE STUDIES FOR ROUTE DIVERSION

- APPLICABILITY: Auditory messages, Navigation, Units of Information, General Messages, Alerting Signs, Radio Messages
- DOCUMENT AUTHOR(S), SOURCE, DATE: Gatling, F.P.
  Traffic Systems Division
  Office of Research and Development
  Federal Highway Administration
  Final Report, June 1975
- DOCUMENT IDENTIFICATION NO. FHWA RD-75-73

Four studies on auditory messages to motorists are reported. The results in Studies 1 and 2 indicate that drivers can handle up to four units of route information successfully. When the messages contain more than four units of information, drivers make unacceptably large numbers of errors when attempting to follow a route. Study 3 showed that drivers could choose and retain general information from auditory messages in which they had an interest and that the difficulty of the message was increased as exit and route numbers were increased. Study 4 developed information on the lead distances that visual signs alerting motorists of the availability of auditory information need to be placed from the broadcast areas.

A3-8 FOG DISPERSAL

This paragraph deals with fog dispersal.

a. III8A - STOCKTON FOG DISPERSAL STUDY

- APPLICABILITY: Fog dispersal, fog detector, visibility, instrumentation
- DOCUMENT AUTHOR(S), SOURCE, DATE: Torguson, E.D.; Shirley, E.C.; Skog, J.B.
  California Division of Highways
  Materials and Research Department
  Final Report, May 1972
- DOCUMENT IDENTIFICATION NO. CA-HWY-MR657107-1-72-24

This report describes the work accomplished by the Materials and Research Department in monitoring a fog dispersal operation conducted by World Weather, Inc. in the Stockton area during February and March 1972. The primary purpose of the study was to evaluate the effectiveness of the contractor's truck mounted ionized, water, surfactant fog dispersal technique. A total scatter fog detector was used to detect changes in visibility. A second objective of the study was to determine the potential of total scatter type fog detector for use in future studies.

The visibility improved significantly on six of the 13 passes monitored. However, on only one pass did the visibility improve from a restricted sight distance to 500 feet (152.4 m) or better, based on the collected data. It was concluded that the fog dispersal technique used by World Weather did not clearly demonstrate effectiveness for high speed highway purposes. The total scatter fog detector was found to be a valuable tool for detecting changes in visibility. The Materials and Research Department recommended that future fog dispersal techniques be tried in a fog chamber prior to atmospheric testing.

b. III8B - FOG DISPERSAL: A TECHNOLOGY ASSESSMENT

- APPLICABILITY: Countermeasures against fog
- DOCUMENT AUTHOR(S), SOURCE, DATE: Weinstein
  Journal of Aircraft, Vol. 14, No. 1, pages 38 to 43, January, 1977
- DOCUMENT IDENTIFICATION NO. None

This paper describes the concepts and recent developments in warm and supercooled fog dispersal and presents the evidence for recent optimism in the operational implementation of these concepts. All fog is divided into one of three categories: Ice Fog, Supercooled Fog, or Warm Fog. Ice Fog (i.e., clouds of ice particles) remains a rare but stubborn phenomenon whose dispersal is presently only in the conceptual stage of development. Intensive research and development over the past decade has led to operational implementation of several techniques for the dispersal of supercooled fog and several promising concepts for the artificial dissipation of warm fog. The dispersal of supercooled fog and stratus (i.e,, liquid water clouds at temperatures below 32° F (0° C) was the objective of the early weather modification experiments and is presently the only truly operational modification technology. Recent developments in the dispersal of warm fog (i.e., clouds of droplets at temperatures above 32° F (0° C) have brought that undertaking to the brink of widespread operational implementation.

Section A4

RVG SYSTEM EQUIPMENT

A4-1 INTRODUCTION

This section contains literature on various types of equipment which can be applied in RVG systems.

A4-2 FOG DETECTORS

Backscatter, forward scatter, total scatter, transmission type, Laser type, and optical contrast types are discussed.

a. IV2A - VIDEOGRAPH DESCRIPTION, OPERATION AND TECHNICAL SPECIFICATIONS

• APPLICABILITY:	Fog detection equipment (backscatter type), technical specifications
• DOCUMENT AUTHOR(S), SOURCE, DATE:	FF Impulsphysics Hamburg, West Germany U.S. Distributor: Karl Scientific Instrument Corp. El Cajon, California 92022
• DOCUMENT IDENTIFICATION NO.	None

The Videograph is a visibility meter based on the measurement of back-scattered light. The instrument consists of a pulsed light projector and a photo-sensitive receiver mounted above it in the same unit. The projector emits a narrow beam of parallel light into the atmosphere. This beam intersects the axis of the receiver at a distance of about 16.4 feet (5 m) in front of the Videograph. Aerosol particles in this zone scatter some of the light in the projector back into the receiver and indicated on a meter graduated in visibility. When the visibility falls below a pre-set level a built-in alarm device closes a pair of contacts for the activation of warning equipment (e.g., sign, etc.). Available accessories are a recorder and two types of direct visibility indicators, one equipped with an alarm-tripping device for up to eight visibility levels. The pertinent specifications are as follows:

• Pre-selected Visibility Range,	330 to 6,600 feet (100.6 m to 2,012 m)
• Power Requirement,	110 or 220 vac or 12/24 vdc; consumption: 65 watts (includes heater operation)
• Physical Dimensions,	pedestal mounting, 47 (length) by 17 (width) by 64 (height) inches (119.4 cm by 43.2 cm by 162.6 cm)

b. IV2B - AGA FOG DETECTOR, MODEL FDBV-100, DESCRIPTION, OPERATION AND TECHNICAL SPECIFICATIONS

- APPLICABILITY: Fog detection equipment (backscatter type), technical specifications
- DOCUMENT AUTHOR(S), SOURCE, DATE: Agatronics Limited Toronto, Ontario M874x4
- DOCUMENT IDENTIFICATION NO. None

The FDBV-100 is a fog detector of the one station, backscatter type. It can be set to any required visibility distance between 0.1 and 6 nautical miles (.18 km to 11 km). When visibility falls below the pre-set visibility distance, the fog detector starts the signal system and keeps it switched on until the visibility rises above the threshold level. In addition, the FDBV-100 has a built-in meter which gives a continual read out of visibility range, and an output which can be relayed to a visibility recorder. Pertinent specifications are as follows:

- Visibility Alarm Level, Adjustable between 0.1 and 6 nautical miles (0.18 km to 11 km) meteorological visibility
- Power Requirements Operation 12 vdc; consumption including window heaters, 15 watts at 12 vdc
- Operating Temperature Range -22° F to 113° F (-30° C to 45° C)
- Physical Dimensions 48 (length) by 20 (width) by 16 (height) inches (121.9 cm by 50.8 cm by 40.6 cm)
- Weight 90 lbs. (40.8 kg)

c. IV2C - EDISON FOG DETECTOR, MODEL 905872, DESCRIPTION, OPERATION AND TECHNICAL SPECIFICATIONS

- APPLICABILITY: Fog detection equipment (forward scatter type), technical specifications
- DOCUMENT AUTHOR(S), SOURCE, DATE: Edison Instrument Division Laboratory
- DOCUMENT IDENTIFICATION NO. None

The fog detector developed by Thomas A. Edison Instrument Division Laboratory relates the intensity of scattered light in the forward direction to the horizontal visibility range. The system consists of two units: a transmitter of ultra-violet radiation and a receiver of the scattered radiation. Since the receiver responds only to ultra-violet radiation, it is insensitive to daylight and works equally well by day or night. The two units face each other about three feet (0.91 meters) apart. The fog density is measured in the immediate vicinity of the instrument. Pertinent specifications are as follows:

- Input Power — 120 vac, 60 cps
- Read-out — 0 to 90 vdc (two-position switch)
- Operating Distance — 26 to 30 inches (66 cm to 76.2 cm)

d. IV2D - FORWARD SCATTER METER, MODEL 207, DESCRIPTION, OPERATION AND TECHNICAL SPECIFICATIONS

- APPLICABILITY: — Fog detection equipment (forward scatter type), technical specifications
- DOCUMENT AUTHOR(S), SOURCE, DATE: — EG&G Environmental Equipment Division Waltham, Mass. 02154
- DOCUMENT IDENTIFICATION NO. — None

The forward scatter meter measures atmospheric forward scattering coefficient in the range of 20 to 50 degrees. In the absence of absorption this is a measure of extinction coefficient and therefore of visual range. The instrument consists of a light source and photo detector separated by approximately four feet (1.2 m) and mounted from a common electronics enclosure. The light source is configured to project a cone-shaped beam of light over the angle of 20 to 50 degrees from the center axis toward the photo detector. The silicon photo detector looks toward the light source and is similarly configured to accept light only from a cone-shaped volume of the same dimensions. Light energy impinging on the photo detector from scattering caused by particulates or aerosols in the sampling volume is linearly related to the extinction coefficient. Logarithmic converters are optionally available to provide convenient display of visual ranges from 200 to 20,000 feet (0.61 km to 6.1 km). The instrument can be calibrated by an accessory item. Pertinent specifications are as follows:

- Visual Range — 200 to 20,000 feet (.061 to 6.1 km)
- Sample Measurement Volume — 1.7 cubic feet (.139 cubic m)
- Measurement Accuracy — Five percent of forward scattering coefficient

- Power — 115 vac ±10%, 60 cycle ±5%, Single Phase: 200 Watts
- Ambient Temperature — -22° F to 122° F (-30° C to 50° C)
- Weight — 135 lbs. (61.2 kg)

e. IV2E - FUMOSENS FOG DETECTOR, DESCRIPTION, OPERATION AND TECHNICAL SPECIFICATIONS

- APPLICABILITY: — Fog detection equipment (forward scatter type), technical specifications
- DOCUMENT AUTHOR(S), SOURCE, DATE: — FF Impulsphysics Hamburg, West Germany U.S. Distributor: Karl Scientific Instrument Corp. El Cajon, California
- DOCUMENT IDENTIFICATION NO. — None

The Fumosens Fog Detector consists of a projector (flash lamp) and a receiver (photo-diode) mounted at opposite ends of a common electronics box between which are placed screens so that no direct light, or light scattered through an angle of less than 20 degrees, can reach the receiver from the projector. In clear air no light from the projector reaches the receiver. However, when visibility is poor, some light is scattered towards the receiver by the fog particles. The resulting output current in the receiver circuit may be used to operate relays controlling fog warning devices at pre-set values of current and hence of visibility up to three levels of fog intensity can be selected to activate fog warning devices. Pertinent specifications are as follows:

- Visibility Threshold Output — Up to three levels
- Power Requirements — 110 or 220 vac Consumption is 20 watts continuous, 60 watts for heater
- Operating temp. range — -22° F to 113° F (-30° C to 45° C)
- Mounting and Weight — Pole mounted unit, 45 lbs. (20.4 kg)

f. IV2F - TOTAL SCATTER, FOG VISIOMETER, MODEL 1580, DESCRIPTION AND TECHNICAL SPECIFICATIONS

• APPLICABILITY:	Fog detection equipment (total scatter type) technical specifications
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Meteorology Research, Inc. Altadena, California 91001
• DOCUMENT IDENTIFICATION NO.	None

The MRI Model 1580 Fog Visiometer was developed based on the integrated scattering principle of the MRI Integrated Nephelometer. The Visiometers in-situ design allows continuous measurement without disturbing the atmosphere. The air sample is illuminated by a pulsed Xenon lamp, and light scattering from the sample volume is measured by a photomultiplier and associated solid state circuitry. A controlled viewing background is provided by a fixed light trap which is a permanent part of the assembly. The circuitry only sees the sample volume at the time of the flash of the lamp and, therefore, eliminates interferences from background lighting or nearby light sources. The optical surfaces are continuously flushed with heated, particle free air to prevent condensation and to ensure the long term stability and accuracy of the instrument readings. Instrument calibration is provided by a two point system which operates independently of prevailing visibility. The instrument is normally calibrated for measurements of visibilities between 260 feet to two miles (79.2 meters to 3.2 km). A wide range of adjustment is provided, 6 miles to 25 feet (9.7 km to 7.6 meters) depending on the application. The internal calibrator can be remotely actuated.

Pertinent specifications are as follows:

• Accuracy	Minimum accuracy is to within 15 percent of scattering coefficient in normal atmospheric haze, fog, and precipitation
• Range	Any factor of 100 in visibility within local span of 25 feet to 15 miles (7.6 meters to 24.1 km) can easily be set in field. Over-range capability is present at both ends of scale, but at a reduced accuracy
• Input Power	105-125 vac, 60 Hz, 50 watts max.
• Weight	43 pounds (19.5 kg)
• Ambient Temperature Range	-22° F to 122° F (-30° C to 50° C) for operation within accuracy
• Size	53 (length) by 6.5 (width) by 11.5 (height) inches (134.6 cm by 16.5 cm by 29.2 cm)

g. IV2G - TRANSMISSOMETER, TYPE ELTRO TM-75D, DESCRIPTION AND OPERATING INSTRUCTIONS

- APPLICABILITY: Fog detection equipment (transmission type), technical specifications
- DOCUMENT AUTHOR(S), SOURCE, DATE: Eltro GmbH and Company, Gesellschaft für Strahlungstechnik, Heidelberg, Germany, August 1972
- DOCUMENT IDENTIFICATION NO. TS-D72047

Description of an optical transmitter and receiver of visible light, with operating instructions. Consists of a sensor unit (optical transmitter and receiver), a remote passive reflector unit on a tripod, an indicator unit and associated cabling. Pertinent specifications are as follows:

- Baseline Length: 246.1 feet (75 m)
- Lightpath Length: 492.1 feet (150 m)
- Spectral Range: 440 to 650 millimicrons*
- Power Supply: 220 v (+ 10%), 50 Hz
- Power Consumption: Sensor optics with heating: 150 w; Indicator: 30 w
- Operating Temperature Range: Sensor: -31^{o} F to 131^{o} F (-35^{o} C to 55^{o} C); Indicator: -4^{o} F to 113^{o} F (-20^{o} C to 45^{o} C)

h. IV2 H - SKOPOGRAPH DESCRIPTION, OPERATION AND TECHNICAL SPECIFICATIONS

- APPLICABILITY: Fog detection equipment (transmission type), technical specifications
- DOCUMENT AUTHOR(S), SOURCE, DATE: FF Impulsphysics, Hamburg, West Germany; U.S. Distributor: Karl Scientific Instrument Corp., El Cajon, California 92022
- DOCUMENT IDENTIFICATION NO. None

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*One millimicron = 10^{-9} meter

The Skopograph measures visibility using the transmissometer principle - i.e., it measures the amount of light removed from the beam of a projector by scattering and absorption in traversing the atmosphere along the baseline between projector and receiver. Measurement accuracy is achieved for visibilities with the range from two-thirds to 20 times the baseline based on a 2 percent threshold of luminance contrast. Skopograph consists of a pulsed light projector, a receiver and a recorder. It normally uses a baseline of 246.1 feet (75 m) giving a measuring range of 165 to 4,925 feet (50 to 1,500 m), in terms of standard visibility.

The projector emits light pulses of high intensity and short duration in the direction of the receiver, which is set up a known distance away. A restriction of visibility between projector and receiver corresponds to a decrease in the light pulses entering the receiver. The scale of the recorder, which responds continuously to the quantity of light received is graduated in transmission factor and visibility. An optional direct indicator permits continuous checking of the measured values of visibility. In addition, an alarm-tripping device is available which will operate visual or audible warning signals at up to eight points on the visibility scale. Pertinent specifications are as follows:

• Visual Range	165 to 4,925 feet (50.3 m to 1,501.1 m) (eight visibility threshold levels with optional alarm device)
• Separation Projector/ Receiver	1,475, 490, or 250 feet (450, 150 or 75 m)
• Power Requirements	220 vac Power Consumption Projector: 370 watts Receiver: 285 watts
• Physical Dimensions	Projector: 43 (length) by 17 (width) by 61 (height) inches (109.2 cm by 43.2 cm by 154.9 cm) Receiver: 38 (length) by 13 (width) by 57 (height) inches (96.5 cm by 33.0 cm by 144.8 cm) (both units are pedestal mounted)
• Weight	Projector: 120 lbs (54.4 kg); Receiver: 115 lbs (52.2 kg)

i. IV2I - HIGHWAY SAFETY FOG DETECTOR, MODEL 172B, MANUAL: VISIBILITY MONITOR SYSTEM

• APPLICABILITY:	Fog and dust detection equipment (transmission type), technical specifications
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Colorado Electro-Optics Boulder, Colorado 80301
• DOCUMENT IDENTIFICATION NO.	None

The Model 172B is a visibility sensor for detecting natural or man-caused conditions due to fog or dust. Using a fixed position transmitter-receiver pair, the system beams modulated light in the near infra-red to a transmissometer, sensitive only to the coded beam. Thus this receiver is nearly immune from other light sources. Whenever the visibility drops below a predetermined level, the receiver switches power to a remote load to indicate impaired visibility. The system uses solid state circuitry. The transmitter and receiver units contain a thermostatically controlled heater for the lens which allow for operation in all weather. The operational range is 250 to 1,000 feet (76 m to 300 m). Broad beam divergence gives necessary alignment stability. The manufacturer provides many options to the visibility sensor including multiple, independently set thresholds, variable activation and deactivation delays, and an analog output proportional to visibility. Pertinent specifications are as follows:

• Transmitter/Receiver Separation	250 to 1000 feet (76 to 300 m)
• Visibility Threshold Adjustment Range	200 to 2,000 feet (61 to 610 m) visibility (at 300 foot (91.4 m) separation)
• Power Requirements	110 to 120 vac, 60 Hz (100 watts/set maximum)
• Output	Switched 117 vac, 500 watts
• Size	Transmitter: 5 (length) by 7 (width) by 13 (height) inches (12.7 cm by 17.8 cm by 33.0 cm) Receiver: 2.5 (length) by 4 (width) by 13 (height) inches (6.4 cm by 10.2 cm by 33.0 cm)
• Temperature Range	-30^{o} F to 130^{o} F (-34.4^{o} C to 54^{o} C)

j. IV2J - LASER, VISIBILITY SENSOR, MODEL VS-1, DESCRIPTION AND TECHNICAL SPECIFICATIONS

- APPLICABILITY: Fog detection equipment (laser type), technical specifications
- DOCUMENT AUTHOR(S), SOURCE, DATE: International Laser System, Inc. Orlando, Fla. 32804
- DOCUMENT IDENTIFICATION NO. None

The Model VS-1 Visibility Sensor is a base line visibility sensing device using an eye-safe laser light source. The VS-1 provides separate relay enclosures at four different factory-set levels of reduced visibility. The transmitter and receiver units can be mounted on circular pipes buried in cement. The power and signal cable are connected via a pipe conduit fitting located in the base of the transmitter and receiver. The units are aligned by a built-in panel meter, self-contained heaters keep the transmitter and receiver windows clear during fog or snow conditions. Pertinent specifications are as follows:

- Distance between transmitter and receiver: 250 $\pm$10 feet (76.2 $\pm$3.05 m)
- Receiver signal outputs at different visibilities:
  - Greater than 1,000 feet (304.8 m)
  - Between 1,000 and 500 feet (304.8 to 152.4 m)
  - Between 500 and 300 feet (152.4 to 91.4 m)
  - Between 300 and 100 feet (91.4 to 30.5 m)
  - Less than 100 feet (30.5 m)
- Prime Power: 115 or 220 volts, 50/60 Hz, 30 watts, each end
- Size
  - Transmitter: 8.6 (diameter) by 24 (high) inches (21.8 cm by 61 cm)
  - Receiver: 8.6 (diameter) by 24 (high) inches (21.8 cm by 61 cm)
- Weight
  - Transmitter: 25 lbs. (11.3 kg)
  - Receiver: 25 lbs. (11.3 kg)

k. IV2K - VISIBILITY DISTANCE SENSOR DESCRIPTION, OPERATION AND TECHNICAL SPECIFICATIONS

- APPLICABILITY: Fog detection equipment (optical contrast type), technical specification
- DOCUMENT AUTHOR(S), SOURCE, DATE: Photobell Company New York, N.Y. 10010
- DOCUMENT IDENTIFICATION NO. None

The equipment consists of a viewing target used to simulate a typical roadway obstacle (e.g., the rear of a vehicle) and a target illuminating and sensing device located approximately 250 feet (76.2 m) upstream. The illuminating device is equivalent to vehicle headlights, and is used (in an occasional flash mode) during periods when headlights would normally be used. The sensor measures the contrast of the target and outputs a visibility distance.

l. IV2L - A LOW COST FOG DETECTOR DEVELOPED FOR USE ON ROADS

- APPLICABILITY: Fog detector instrumentation, transmissometers, photo detectors, infrared sources
- DOCUMENT AUTHOR(S) SOURCE, DATE: Jeffery, D.J. Transport and Road Research Laboratory Department of the Environment, England, TRRL Report LR-453, 1972
- DOCUMENT IDENTIFICATION NO. LR-453

A fog detector of the split beam transmissometer type is described. Two light beams, derived from a single modulated solid state source, are detected at the ends of two separate paths, one enclosed and one through the atmosphere. The outputs from the detectors are switched and combined in such a way that the final output is a direct measure of the attenuation undergone by the fog path beam, and is free from zero drift, the effects of ambient light admitted into the apparatus, and photodetector leakage currents.

m. IV2M - FOG DETECTORS FOR CONTROLLING CHANGEABLE MESSAGE SIGNS

- APPLICABILITY: Types of fog detectors
- DOCUMENT AUTHOR(S), SOURCE, DATE: Spear, E.D. Highway Research Board Special Reports Special Report 129, pp. 20-3
- DOCUMENT IDENTIFICATION NO. None

Three instruments that will continuously and automatically measure visibility, detect fog, or do both are the forward-scatter Fumosens, the back-scatter Videograph, and the transmissometer Skopograph; these instruments are manufactured by Impulsphysik, GmbH, Hamburg, West Germany and have recently been introduced into the USA. Table compares the characteristics - visibility range, output signal, power, operating temperature, operating humidity, weight, base, and calibration - for each instrument.

n. IV2N - FOG DETECTORS FOR POLICE USE

- APPLICABILITY: Operational procedures for police during reduced visibility conditions, fog detectors
- DOCUMENT AUTHOR(S) SOURCE, DATE: Hinder, R.A. Police Research Services Branch London, England Article in Police Research Bulletin H23, 74, pages 42-51
- DOCUMENT IDENTIFICATION NO. None

The proportion of accidents due to fog is higher on motorways than on other roads and such accidents are more severe. The author discusses the role of the police in changing the method of operating motorways with a view to greater safety and describes two types of equipment developed by the Plessey Radar Company to measure visibility: a fog density meter and a background light meter. Scientific and operational evaluations of these are outlined. The installation of the first operational site and the collection of scientific data are being arranged by the Transport and Road Research Laboratory.

o. IV2O - FOG WARNING: A STEP TOWARDS AUTOMATION IN ACCIDENT PREVENTION

- APPLICABILITY: Fog detector (transmissometer) usage, effectiveness of detector when used as part of a warning system
- DOCUMENT AUTHOR(S), SOURCE, DATE: Michaelis, E.E. Roads and Road Construction London, England Dec. 71, Vol. 49, No. 588, pages 430-431
- DOCUMENT IDENTIFICATION NO. None

So far, fog warning systems installed in Britain have proved to be of limited value because motorists have found the arrangements under which these are switched on to be unreliable. The light obscuration caused by fog at British airports is measured at three points along the runways using special transmissometers. The ambient light is also measured using a background luminance monitor. The transmissometer is not only highly accurate initially, but maintains its accuracy over a long period of time without requiring constant cleaning. Special housing insures that the instrument will remain operative under the most severe weather conditions. The transmissometer has been used with dramatic reduction of accidents on the Aachen-Cologne Autobahn near a plant producing a severe and localized fog.

p. IV2P - LIMITED VISIBILITY DETECTOR EVALUATION

- APPLICABILITY: Comparison of fog detectors; use of utility model for evaluation
- DOCUMENT AUTHOR(S) SOURCE, DATE: Dale, R.F. New Jersey Turnpike Authority, April 15, 1977
- DOCUMENT IDENTIFICATION NO. None

This report describes a test procedure and evaluation of five commercially manufactured Visibility Detectors for potential application on the New Jersey Turnpike. The tests spanned a period of three fog seasons beginning in the autumn of 1975 and continuing for 14 months. The purpose of the tests was to determine which limited visibility detector most accurately defines visibility levels as seen with the human eye and which were most responsive to changes in visibility levels. Other criteria were ease of installation, high reliability and least maintenance. Field tests were made of each unit in the vicinity of exchange 16W on the New Jersey Turnpike.

Results of the tests are presented and final evaluation and selection were based on a Utility/Cost model. The units tested are listed below:

- International Laser System VS-1 Visibility Sensor
- Meteorology Research, Inc. Visiometer Model 1580A
- Photobell Company Type 4784 MF Fog Transmissometer
- FF Inpulsphysics Corp. Videograph Model B
- McGraw Edison Fog Responder Model 905872

A4-3 VEHICLE DETECTORS

Vehicle detectors are discussed here.

a. IV3A - STUDY OF DETECTOR RELIABILITY FOR A MOTORIST INFORMATION SYSTEM ON THE GULF FREEWAY

• APPLICABILITY:	Reliability of vehicle detectors for use in motorist warning system, method of study, analysis of detector subsystem reliability effectiveness, failure and repair rates, analysis of single warning device
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Dudek, C.L. and Messer, C.J. Texas Transportation Institute, Texas A&M Univ. Dutt, A.K. University of North Carolina at Chapel Hill Transportation Research Board Record 495
• DOCUMENT IDENTIFICATION NO.	None

An experimental warning system has been installed on the Gulf Freeway in Houston as a means of alerting drivers approaching crest-type vertical curves to stoppages downstream of the crest. Successful automatic operation of the warning system depends on the reliability of system components. Earlier studies showed that developed control logic is responsive to stoppage waves, provided that the hardware functions properly. A one-lane control criterion resulted in 100 percent detection whereas 96 percent of the waves were detected using a two-lane control criterion. The studies also indicated a relatively high frequency of detector failures. The frequency of detector failures prompted a study to evaluate reliability of the warning system based on detector failure and repair rates experienced on the Gulf

Freeway surveillance and control system and to ascertain whether detector redundancy or improved maintenance would be necessary. Malfunctions and repairs of all the Gulf Freeway surveillance and control hardware, including the 96-detector subsystem, were recorded for a five month period. The data revealed that the detectors on the Gulf Freeway failed at a rate of 3.78×10^{-4} failures per detector hour. Detectors were repaired at a rate of 0.23 repairs per hour. The reliability in terms of availability of the safety warning system was analyzed using these data and classical models for maintained systems. Availability of the system was 0.95 and 0.995 for the one and two lane criteria respectively. The results indicated that the current detector configuration and maintenance practices were adequate.

A4-4 SIGNS

Sign design and evaluation are included here.

a. IV4A - TOWARD THE DEVELOPMENT OF A METHODOLOGY FOR EVALUATING HIGHWAY SIGNS BASED ON DRIVER INFORMATION

• APPLICABILITY:	Evaluation of highway signs, field data collection, experiment design
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Bhise, V.D. and Rockwell, T.H. Ohio State University Paper sponsored by TRB Committee on Motorist Information Systems
• DOCUMENT IDENTIFICATION NO.	None

This paper presents the findings of a research study conducted to develop a methodology for evaluating road signs by the use of an eye-marker camera as a primary research tool. The methodology attempts to evaluate a road sign by determining the degree of match between the sign-reading behavior of drivers and the characteristics of the signs, the highway, and the traffic situations. Data were collected on the eye movements of drivers under actual driving situations involving more than 400 different Interstate highway signs. The data were analyzed by specially developed computer programs that also computed sign evaluation measures describing sign-reading behavior of the drivers. Further analyses showed that the sign evaluation measures were related to many factors associated with the characteristics of the signing, the driver, the highways, and the traffic situations. Understanding how various factors influence sign-reading behavior provides a basis for the implementation of the methodology for both the evaluation and the design of highway signing.

b. IV4B - LEGIBILITY AND BRIGHTNESS IN SIGN DESIGN

- APPLICABILITY: Sign design, legibility and brightness, minimum letter height requirements, sign positioning, visual equity
- DOCUMENT AUTHOR(S) SOURCE, DATE: Alder, B.A., AIL , Division of Cutler Hammer, Inc. and Straub, A.., Clarkson College of Technology Highway Research Board, No. 366
- DOCUMENT IDENTIFICATION NO. None

An important but neglected aspect of sign design is the choice of letter heights to satisfy nighttime legibility requirements. In choosing letter heights, the fundamental relationship of brightness and legibility must be taken into account. Sign brightness is a function of many factors including sign material and position, road alignment, and vehicle and headlight characteristics. A computer program was developed that incorporates these factors and determines sign brightness as a function of road distance. The distance at which the sign must be first legible is used in conjunction with the computed brightness and published empirical data relating brightness to legibility to calculate required letter heights. Minimum letter height requirements for road distances up to 2,000 feet (609.6 m) are presented. The cases reported include a straight road, high and low headlight beams, six sign positions, four horizontal alignments, and four vertical alignments. For nighttime legibility, it was found that required letter heights are much larger than the 50 feet per inch (6 meters per centimeter) rule indicates. Because of the widely varying sign brightness found in actual roadway conditions, each sign should be treated individually as a separate design problem.

c. IV4C - VARIABLE MESSAGE SIGNING FOR TRAFFIC SURVEILLANCE AND CONTROL

- APPLICABILITY: State-of-the-art and current research in variable message signing
- DOCUMENT AUTHOR(S), SOURCE, DATE: Warren Dorsey DOT, FHWA, Office of Research and Development - January, 1977
- DOCUMENT IDENTIFICATION NO. FHWA-RD-77-98

This report is a state-of-the-art summary of variable message signing (VMS) technology currently utilized for traffic control applications. The report briefly describes the four basic components of a VMS system. These are the VMS display, VMS control system, VMS system interconnect, and VMS highway surveillance system.

The report focuses on the VMS display. It covers the following nine display types: flap, scroll, drum, inert gas (neon), fiberoptics, light bulb matrix, electromechanical flap matrix, electrostatic vane matrix, and electromagnetic disc matrix. For each display type its functional characteristics, manufacturer, operational experiences, and currently available publications are presented. The final section of the report describes current VMS research activity being undertaken by the federal government and by the VMS manufacturers.

A4-5 COMPUTERS

The use of computers is covered in this part.

a. IV5A - ANALOG VISIBILITY COMPUTER

• APPLICABILITY:	Use of a computer for calculating visual range
• DOCUMENT AUTHOR(S) SOURCE, DATE:	Horner, J.L. Applied Optics Vol. 15, No. 4, April 1976
• DOCUMENT IDENTIFICATION NO.	None

This paper describes a simple, inexpensive, all solid-state analog computer that has been developed for calculating the visual range. Using an input signal from a transmissometer, the computer calculates the visual range by repeatedly solving the Allard and Koshmieder visibility laws. It is accurate to 2.0 percent for visual ranges of between 500 feet (150 m) and 5,000 feet (1,500 m).

A4-6 CLOSED CIRCUIT TELEVISION

The use of closed circuit television is discussed here.

a. IV6A - REMOTE MONITORING OF VISIBILITY IN MOUNTAIN PASSES

• APPLICABILITY:	Usage and evaluation of television to monitor visibility conditions
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Equipment Development Laboratory National Oceanic and Atmospheric Administration Sponsored by Federal Aviation Administration Final Report, April 1974
• DOCUMENT IDENTIFICATION NO.	DOT Contract No. FA72WAI-244

This report describes the work accomplished and results obtained during an experimental program that evaluated television and slow-scan video transmission techniques as a means to remotely monitor visibility in mountain passes. The purpose of the program was to demonstrate the practicality of this technique to provide Visual Flight Rules (VFR) pilot advisories in remote mountain passes. The investigation was divided into three phases. Phase I consisted of site selection, detailed system design, and the establishment of a test plan. Phase II consisted of equipment procurement and installation, test operation for five months, and system evaluation. The results from Phase II demonstrated the feasibility of providing adequate VFR visibility. VFR visibility versus visibility viewed on TV monitors showed good correlation. The television equipment used in the study was off-the-shelf commercial equipment and its reliability was good considering that the equipment was not designed specifically for the severe weather conditions experienced. Phase III of the study consisted of generating specifications for procuring future systems on a competitive basis.

A4-7 VEHICLE MOUNTED GUIDANCE LIGHTS

Special lights mounted on vehicles are discussed in this part.

a. IV7A - SEEING THROUGH FOG

- APPLICABILITY: Vehicle mounted equipment for seeing through fog, potential usage in police patrol cars
- DOCUMENT AUTHOR(S), SOURCE, DATE: Industrial Research Jan. 69, Vol. 11, No. 1, pages 17 to 19
- DOCUMENT IDENTIFICATION NO. None

A viewing system has been developed that allows an observer to see through fog, snow, rain, storms, foliage, forests, and screen mesh. Using a gallium-arsenide laser, Laser Diode Laboratories have developed a gated infrared illuminator device that is portable and low-cost. The device has a range from 16.4 feet to 328.1 feet (5 m to 100 m), depending on conditions. About 20 watts of input power are required by the system. The lasers are pulsed and a short burst of light travels out and returns to the transceiver. An image intensifier tube in the device is maintained in the off position, preventing the light from striking the photocathode and entering the tube. However, when the leading edge of the reflected laser light from the object strikes the photocathode, the tube is switched on. The result is that the eye of the observer receives only the light reflected from the object. The backscattered light is not of high enough intensity to turn on the image intensifier. The very rapid gating of the tube (10-nsec pulsing) is the key to the device.

b. IV7B - HIGHWAY VISIBILITY IN FOG

- APPLICABILITY: Vehicle mounted lamps, fixed lighting, fog detection and traffic control, equipment
- DOCUMENT AUTHOR(S), SOURCE, DATE: Marsh, C. Pennsylvania State University Paper presented at National Technical Conference of the Illuminating Engineering Society Sept. 9-13, 1957
- DOCUMENT IDENTIFICATION NO. None

This paper presents the results of an investigation conducted by Pennsylvania State University to examine the problem of fog on turnpikes. The project was divided into four parts dealing with Vehicle Mounting Lamps, Fixed Lighting, Fog Detection and Traffic Control, and Equipment.

The main thrust of this paper is oriented towards lighting equipment for vehicles which can be used to help the driver during periods of reduced visibility (fog).

A4-8 REDUCED VISIBILITY DETECTORS FOR BLOWING SNOW

The following pages deal with equipment for determining visibility in blowing snow.

a. IV8A - MEASURING VISIBILITY IN BLOWING SNOW

- APPLICABILITY: Determination of visibility in blowing snow
- DOCUMENT AUTHOR(S) SOURCE, DATE: Schmidt, R.A. Paper presented at Symposium on Driver Visibility Under Varying Adverse Weather Conditions, Portland, Oregon; August 16-18, 1977
- DOCUMENT IDENTIFICATION NO. None

This paper describes an electronic system developed by the USDA Forest Service, in cooperation with the Wyoming State Highway Department, to help travelers avoid being stranded in blowing snow storms and to improve the safety of transportation under drifting conditions. The system consists of an anemometer, a blowing snow sensor, and a specialized analog computer designed to combine signals from the sensors according to an equation for visual range. The sensor for blowing

snow consists of a photoelectric particle counter that produces a voltage pulse for each snow particle which passes through a 0.012 inches by 0.984 inches (3 mm by 25 mm) area normal to the wind. The sensor's pulse train is electronically processed to give voltages proportional to five second averages of particle frequency and diameter. This paper presents the derivation of the visibility equation, a full description of the blowing snow sensor and the electronic analog computer. The procedure and results of field calibration of the system are explained and an example of the strip chart record leads to a discussion of the usefulness and application of the system. Field calibration was accomplished by comparison with closed circuit television recordings of visual range targets during drifting. The correspondence between theory and observed visual range was very satisfactory, and two such systems are now in use for traffic control in Wyoming, having proved reliable and useful during three winters.

b. IV8B - VISIBILITY IN BLOWING SNOW AND APPLICATIONS IN TRAFFIC OPERATIONS

- APPLICABILITY: Visibility parameters related to environmental parameters in snow
- DOCUMENT AUTHOR(S), SOURCE, DATE: Tabler, R.D. Paper presented at Symposium on Driver Visibility Under Varying Adverse Weather Conditions, Portland, Oregon; August 16-18, 1977
- DOCUMENT IDENTIFICATION NO. None

This paper presents results of experiments made in Wyoming exploring the relationship between wind and visibility, with emphasis on changes accompanying snow cover depletion, and shows how this information is used for traffic operations. In the experiment, wind and visibility data are continuously transmitted from two monitoring stations on I-80 between Laramie and Rawlins, Wyoming. This data is analyzed in real-time by a computer and summaries of conditions are printed out hourly, with recommended warning messages transmitted when minimum standards are exceeded. Required speed limits are determined by equating "stopping sight distance" to the hourly average minimum visibility and solving for vehicle speed. Studies reported here show that for wind speeds greater than 23 ft/s (7 m/s) in blowing snow, visual range (V) is related to wind speed (U) according to $V = AU^{-5}$, where the A coefficient changes in response to snow availability. The A coefficient calculated from incoming data is used to index snow conditions, predict visibilities based on wind forecasts, and detect snowfall. This information is used for road closure or opening decisions and to estimate time required for visibility to reach the prescribed standard for opening a road.

Computerized analysis of weather data is essential for timely and objective traffic operation decisions, and the relationship between wind and visibility in blowing snow can provide the basis for standards that are technically sound and unambiguous.

Section A5

RVG SYSTEMS DESIGN, INSTALLATION, OPERATION, AND EVAULATION

A5-1 INTRODUCTION

Study literature dealing with the design, installation, operation, and evaluation of RVG systems is presented in this section.

A5-2 FOG

Guidance systems for fog conditions are covered here.

a. V2A - SPEED ADVISORY INFORMATION FOR REDUCED VISIBILITY CONDITIONS

• APPLICABILITY:	Vehicle traffic control, speed control, visibility standards, traffic safety, fog road tests, experimental data, human factors engineering, performance evaluation, night vision in fog
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Lane, F.D.; Pfau, J.L., Oregon State Department of Transportation Interim Report, May 1975
• DOCUMENT IDENTIFICATION NO.	Contract No. DOT-FH-11-7950

The study develops preliminary design specifications for a speed advisory system for use during periods of reduced visibility. Phase I of the program consisted of developing the necessary facilities, equipment, and procedures to conduct controlled experimentation under various levels of fog density. Phase II consists of a series of interrelated experiments to identify optimum advisory information (sign messages and speed values), and the number, locations and interconnections between signs which will result in smooth traffic flow. Phase III will utilize this information, as well as pertinent literature, to develop detailed specifications for a full scale advisory system for testing on a public highway.

This report covers the activities of Phase I and the preliminary results of the first two experiments of Phase II. The first study of Phase II was concerned with determining what speeds drivers normally drive at under various conditions of reduced visibility. The second study was intended to determine which of the percentile speeds from Study I would result in the smoothest traffic flow when used as a posted speed for the various visibility conditions.

The results from the preliminary analysis indicate that the posted speed sign had little or no effect (regardless of which percentile speed was posted) upon driver performance in terms of mean speed through fog. Additionally, the presence of the posted speed was found to have a slightly detrimental effect upon traffic stability. This was evidenced by an increase in speed variance for the conditions of Study II, in which a posted speed was present as compared to the speed variance in Study I, where there was no posted speed. For Study II, little in the way of a systematic effect was found for the posted speeds within visibility conditions.

b. V2B - SPEED ADVISORY INFORMATION SYSTEMS FOR REDUCED VISIBILITY CONDITIONS

- APPLICABILITY: Design specifications for speed advisory system in reduced visibility environment.
- DOCUMENT AUTHOR(S), SOURCE, DATE: Hofstetter, Dwayne K.; Lane, Francis D.; Wagner, Donald R.; Oregon State Department of Transportation, June 1978
- DOCUMENT IDENTIFICATION NO: FHWA-RD-78-32

This report provides preliminary design specifications for a speed advisory system for use during periods of reduced visibility (fog). Phase I of the program consisted of developing the necessary facilities, equipment and procedures to conduct controlled experimentation under various levels of fog density. Phase II consisted of a series of interrelated experiments to identify optimum advisory information (sign messages and speed values), and the number, locations and interconnections between signs which would result in the smoothest traffic flow. Phase III utilizes the information from Phase II, as well as the pertinent literature, to develop preliminary specfications for a full-scale advisory system for use on the public highway.

Phase II contained six separate studies. Study I was concerned with determining the speed drivers normally drive at various levels of reduced visibilities. Study II was to determine which of the three major percentile speeds (15th, 50th, 85th) from Study I would produce smoothest traffic flow when used as a posted speed. The main purpose of the third study was to determine driver response to various highway hazards which may be encoutered under conditions of reduced visibility. The 4th study investigated the effects of different types, amounts and display characteristics of advisory signing. Study IV investigated the utility of centerline and edgeline delineation. The final study dealt with the reliability of advisory signing systems.

c. V2C - EVALUATION OF THE 5.8 MILE HIGHWAY LIGHT SYSTEM FOR GUIDANCE IN FOG ON AFTON MOUNTAIN

- APPLICABILITY: Identification of roadway lighting techniques for motorist guidance during reduced visibility, evaluation procedures for highway light system
- DOCUMENT AUTHOR(S), SOURCE, DATE: Creech, M.F.; Chrissman, T.A. Virginia Highway and Transportation Research Council Evaluation Report, September 1976
- DOCUMENT IDENTIFICATION NO. VHTRC 77-R16

This report presents the results of an evaluation of a 5.8 mile (9.3 km) fog guidance system light system on I-64 across Afton Mountain. Briefly described, the system is divided into three contiguous sections. The lights within each section are automatically controlled (activation, brightness control and deactivation) by fog detectors. The sections act independently and the lights are only activated in those sections where fog is present. Two types of lights are utilized in the system, pavement insert and low level illumination lights. The pavement insert lights are installed along the roadway edge lines (including ramps) to form a guidance system for motorists to follow when visibility is reduced to the extent that the pavement markings cannot be seen. The low level illumination lights are mounted above ground and are used to increase the drivers sight distance during reduced visibility conditions. These lights were not included in the evaluation.

The data for the evaluation of the system was obtained through a survey questionnaire and interviews with highway employees, local residents, professional truck drivers and travellers who cross Afton Mountain frequently. The survey responses were overwhelmingly positive which indicated that even the slightest aid to motorists who must travel through dense fog is greatly appreciated. For example, 97 percent of the people said that the lights either formed a pattern for the vehicle to follow or helped in outlining road edges. Approximately 90 percent indicated that the lights reduced anxiety of driving in fog. On the other hand, the surveyed motorists indicated that the lights did not increase the visibility of vehicles ahead. Since this evaluation survey was performed while the system was still new and novel, during a period when there were problems with the control system operation, the authors recommend that a similar evaluation be made one year hence. The results of previous evaluation surveys could then be compared.

d. V2D - VARIABLE MESSAGE FOG HAZARD WARNING SIGNS TO CONTROL VEHICLE OPERATING CHARACTERISTICS

- APPLICABILITY: Evaluation of variable message signing in controlling traffic during periods of reducing visibility, vehicle detector applications
- DOCUMENT AUTHOR(S), SOURCE, DATE: Oregon Department of Transportation State Highway Division, Traffic Engineering Section Interim Report, April 1972
- DOCUMENT IDENTIFICATION NO. Oregon HPR-1(6)

This project is aimed at determining the effectiveness of variable message signs in controlling traffic on an Interstate Highway during periods of hazardous driving conditions such as fog, vehicle accidents or congestion. There are six variable message signs in the system (3 in each direction) along a 6 mile (9.3 km) section of Interstate I-5 near Albany, Oregon. Associated with these signs, a series of twenty inductive loop detectors were installed. A mini-computer is used with the loop detectors to derive vehicle speed and headway data. The effectiveness of the signs is being measured quantitatively by use of accident records, vehicular speeds, and headways. Insufficient data was collected during the study period which precluded drawing quantitative conclusions. However, based on data available, interviews with the State Police, and visual observation of vehicular operations, it appears that the signs are effective in controlling traffic operations and thereby preventing accidents during periods of reduced visibility, due to fog.

e. V2E - INSTALLATION REPORT ON A FOG GUIDANCE LIGHT SYSTEM ON AFTON MOUNTAIN

- APPLICABILITY: Installation of fog guidance light system
- DOCUMENT AUTHOR(S), SOURCE, DATE: Creech, M.F., Virginia Highway and Transportation Research Council Report, August 1976
- DOCUMENT IDENTIFICATION NO. VHTRC 77-R12

This report discusses the installation of the Afton Mountain fog guidance system. The system was installed between May 15, 1974, and March 15, 1976, at a total cost of $1,997,748. It covers a distance of 5.8 miles (9.3 km) along I-64, and consists of 841 pavement inset lights spaced at 200 foot (61 m) intervals on tangent sections and at 100 feet (30.5 m) on curved sections on the main line a short distance down the exit ramps at the Afton Interchange; a short section of 50 low elevation roadway lights on ramp AB at the Afton Interchange; six fog detectors strategically located throughout the system; and a building to house the power and control apparatus for the system.

All electrical wiring, whether control or power, is enclosed in conduit. The system comprises conduits buried along both edges of the road in each direction; 1,659 transformer housings located off the road shoulders below the surface set in concrete and in line with the conduit; 251 junction boxes; and 45 electrical splicing boxes.

The system is divided into three contiguous sections, and is automatically controlled by fog detecting devices that turn the lights on and off and adjust the intensity of the lighting to correspond to the level of fog density.

f. V2F - DETECTORS FOR AUTOMATIC FOG WARNING SIGNS

- APPLICABILITY: Evaluation of variable message fog warning signs, fog detector application
- DOCUMENT AUTHOR(S), SOURCE, DATE: Juergens, W.R. Traffic Branch, California Division of Highways Final Report, November 1973
- DOCUMENT IDENTIFICATION NO. CA-DOT-TR-1115-1-73-02

This report discusses the installation and evaluation of variable message fog warning signs to alert motorists to reduced visibility conditions ahead during foggy conditions. Two signs (electrostatic flag matrix type) were installed each at a different site, alongside the abutment on an overpass of Highway 99 (in San Joaquin County) where power and telephone service were readily available. A fog detector (transmissometer type) was placed alongside Highway 99 and was connected to the signs. When the visibility recorded by the fog detector dropped below a preset threshold, a fog warning message was displayed to motorists. After a study period it was learned that the location and size of the sign was not effective enough to catch the driver's eye. It was recommended that signs of this type should be placed on a sign bridge so that it straddles the traffic lanes or at a remote location where other signs or remote features are not competing for motorist attention. There was no evidence that vehicle speeds were reduced when the signs were in operation warning of heavy fog ahead. However, a recommendation was made to use flashing lights when a warning message is displayed to increase the signs attractiveness to the motorist.

g. V2G - FOG WARNING SIGN SYSTEM

- APPLICABILITY: Development of a fog warning system, changeable message signs, fog sensors, vehicle detectors
- DOCUMENT AUTHOR(S), SOURCE, DATE: George, L.E.
  Oregon State Highway Department
  ITTE, California University, Berkeley
  Proceedings 2nd Annual Symposium
  Paper, December 1969
- DOCUMENT IDENTIFICATION NO. None

This paper describes the events that led to the development of a fog warning sign system for a section of Interstate I-5 near North Albany, Oregon. A discussion of the fog accident history for the highway section is presented. The major elements and operation of the fog warning sign system are described.

h. V2H - A RECOMMENDED CONFIGURATION FOR AN ADVERSE WEATHER AND VISIBILITY HAZARD WARNING SYSTEM

- APPLICABILITY: Highway fog problem, guidance for adapting a recommended configuration for a warning system to a specific highway section, conducting an engineering study and justifying controls, methods of evaluating alternative systems.
- DOCUMENT AUTHOR(S), SOURCE, DATE: Office of Traffic Operations
  Federal Highway Administration
- DOCUMENT IDENTIFICATION NO. None

Fog is a highway visibility problem to a hazardous extent in at least 60 percent of the United States. Reduced visibility from snow, blowing sand, and rain constitutes a similar problem in particular geographical areas. The onus to alleviate this problem rests with the States and other authorities operating the highway system.

This report provides guidance for adapting a Recommended Configuration for an Adverse Weather and Visibility Hazard Warning System to specific highway sections. The pivotal act in this function is the traffic engineering judgment as to the speed limits which will optimize traffic flow under the given environmental conditions.

Suggestions are made for conducting an engineering study and justifying controls. The design details of the recommended configuration are described and a method for evaluating any alternative system is included.

i. V2I - TRAFFIC FLOW EVALUATION OF PAVEMENT INSET LIGHTS FOR USE DURING FOG - BEFORE PHASE

- APPLICABILITY: Field measurements of traffic flow characteristics, data collection equipment, traffic data analysis
- DOCUMENT AUTHOR(S), SOURCE, DATE: Shepard, F.D. Virginia Highway and Transportation Research Council, September 1975
- DOCUMENT IDENTIFICATION NO. VHTRC 76-RG

This report summarizes the traffic flow data collected as part of the Before Phase to investigate the effect of the Afton Mountain light guidance system on traffic flow characteristics during periods of reduced visibility (fog). A system of roadway tapeswitches connected to chart recorders was used for data collection. Vehicle speeds, headway and placement were derived from the output of the chart recorders. The data was collected under a variety of visibility conditions. The identification of the fog density for use in the analysis was determined by noting the number of visible centerline strips on the pavement during daylight hours and the number of reflectorized shoulder delineators during hours of darkness. The data collected during the study is presented and analyzed, and its reliability is evaluated. An accident analysis for the highway section was also conducted. Recommendations are made pertaining to the data collection effort for the After Phase portion of the study.

j. V2J - TRAFFIC FLOW EVALUATION OF PAVEMENT INSET LIGHTS FOR USE DURING FOG

- APPLICABILITY: Traffic flow characteristics before and after implementation of a reduced visibility system.
- DOCUMENT AUTHOR(S), SOURCE, DATE: Shepard, Frank D. Virginia Highway and Transportation Research Council, December 1977
- DOCUMENT IDENTIFICATION NO: VHTRC 78-R25

The purpose of this research was to investigate the traffic flow characteristics during fog within the system of pavement inset lights installed on I-64 across Afton Mountain, near Charlottesville, Virginia. The scope of the study included the collection and analysis of traffic flow data before and after the inset lights were installed. The traffic flow parameters evaluated were vehicle speeds, headways, queues, and lateral placement. A before and after accident analysis was also made.

The effect of the system of pavement inset lights on the traffic flow characteristics was determined by comparing data collected before and after the system was

installed. Data were collected for all fog conditions (day and night) occurring within the the time frame allowed for collection. Data collection was limited to weekdays during off-peak hours.

k. V2K - FOG DETECTION AND WARNING SYSTEM

• APPLICABILITY:	Installation of fog warning system, fog detector and warning signs, study plan for evaluating system
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Pennsylvania Department of Transportation Bureau of Traffic Engineering Interim Report No. 1, March 1976
• DOCUMENT IDENTIFICATION NO.	None

This report describes the fog detection and warning system that is presently being installed in the vicinity of Geneva March Bridge on Interstate I-79, near Meadville in Crawford County, Pennsylvania. The system consists of a series of fog detectors and warning signs. The first sign in each direction is located 1.5 miles (2.4 km) in advance of the highway bridge and is a standard size "Fog Area" sign with flashing lights. The flashers will be activated only during fog conditions. The other two signs in each direction are variable message signs with the legend "Speed Limit - Fog". These signs are located 1.5 miles (2.4 km) from the bridge. The speed limits displayed are determined by the fog density indicated by the detectors. Three fog detectors are being installed on the bridge and will be radio connected to the warning signs, activating the signs and establishing the appropriate speed limits. A detailed nine-point plan is outlined to study the effectiveness of the system. The data collected prior to the installation of the system indicates that fog conditions at the bridge did not have a significant effect on vehicle speeds.

A5-3 DUST SYSTEMS

Guidance systems for dust conditions are covered here.

a. V3A - ARIZONA'S DUST WARNING SYSTEM: A REVIEW AND EVALUATION

• APPLICABILITY:	Blowing dust accident problem (weather, driving environment, etc.), Dust Warning System (description and operation), Evaluation (evaluation procedures, data collection, driver behavior, accident and economic analysis, etc.)
• DOCUMENT AUTHOR(S), SOURCE, DATE:	Arizona Department of Transportation Traffic Operations Services Final Report, April 1976
• DOCUMENT IDENTIFICATION NO.	None

This report is a review and evaluation of Arizona's Dust Warning System. The objective of the Warning System is to reduce or eliminate accidents related to dust storms. The system is comprised of 40 changeable message signs located along 82 miles (132 km) of Interstates I-8 and I-10 in Sourth Central Arizona. The study examines the nature of dust storms in detail and concludes that they are complex and highly unpredictable phenomena. The dust storm accident is analyzed to determine the extent of the problem and what factors are generally characteristic of this type of accident. A description of the Dust Warning System and its operation is provided in order to have a better understanding about the elements involved and the sequence of events that occur when a dust storm is detected. The performance of the Dust Warning System is evaluated with respect to its effect on drivers, traffic accidents and economics. Three data sources were used in the evaluation process: before and after accident rates, field observations, and motorist survey via questionnaires. A summary of the more important study findings are as follows:

- No significant difference in before and after accident rates
- Vehicle speeds are independent of sign messages, whether properly displayed or not
- The motoring public expressed a strong desire to receive more information as to what they should do if they encountered a dust storm
- Due to the unpredictability of blowing dust, the present Dust Warning System could not be operated in a timely fashion more than 60 percent of the time.

A5-4 SNOW SYSTEMS

There is no literature on snow systems at this time.

A5-5 MOTORIST ADVISORY SYSTEMS

The following pages deal with systems warning motorists of road and visibility conditions.

a. V5A - EVALUATION OF A PROTOTYPE WARNING SYSTEM FOR URBAN FREEWAYS

- APPLICABILITY: Evaluation of a warning system, method of study, survey questionnaire, cost effectiveness analysis, system effect on primary and secondary accidents
- DOCUMENT AUTHOR(S), SOURCE, DATE: Dudek, C.L; Huchingson, R.D.; Ritch, G. Texas Transportation Institute, Texas A&M University Transportation Research Board Record 533
- DOCUMENT IDENTIFICATION NO. None

This paper evaluates a prototype real-time system that warns approaching motorists of stoppages downstream or cresting vertical curves. Before and after studies were conducted to measure primary and secondary accidents. A questionnaire survey was administrated to obtain motorist reactions. The study results revealed that the warning system is cost effective. Both primary and secondary accidents were reduced. The results of the questionnaire study indicated that motorists believed that the system was useful, that the warning sign was readily noticed, and that the message was generally understandable and appropriate to traffic conditions.

b. V5B - AN EVALUATION OF THE FOLLOWING TOO CLOSELY MONITOR SYSTEM ON A FOUR-LANE UNDIVIDED HIGHWAY

- APPLICABILITY: Following Too Closely Monitor System, Motorist Warning System, signs, before and after effectiveness study, police enforcement
- DOCUMENT AUTHOR(S), SOURCE, DATE: Parker, Jr., M.R. Virginia Highway and Transportation Research Council Final Report, May 1976
- DOCUMENT IDENTIFICATION NO. VHTRC 76-R51

The Following Too Closely (FTC) monitor system is an experimental device designed to measure vehicle gaps at a point along the highway and to advise the motorist, by means of flashing message on a sign, that he is following the car in front of him too closely. On October 31, 1974, ten FTC monitors were installed at four sites on a 6-mile (9.7 km) 4-lane undivided section of Route 1 in Woodbridge, Virginia. As the FTC system is a new concept in highway safety, an investigation was conducted to evaluate the effects of the system on vehicle spacings, speeds, and accidents. Traffic and accident data were collected for a period one year before and one year after the monitors were installed. The results of the study reveal that use of the FTC system resulted in a significant reduction in accidents. A decrease in injury, property damage, and all crash types, including rear end collisions, was found. Monitors located in a suburban area, within a 0.5 mile (0.8 km) section downstream from traffic signals, were found to be more effective in reducing incidents of following too closely accidents than were monitors in rural areas. After nine months of operation, the monitors appeared to begin to lose their effectiveness in decreasing the number of short vehicle gaps and reducing accidents. A minimal police effort was used to issue citations to motorists who were following at unsafe intervals. The enforcement campaign was effective in decreasing the number of short vehicle gaps and reducing accidents. The monitors were found to be cost effective. Further research is recommended to determine the amount of police enforcement necessary to sustain long-term benefits of the system.

c. V5C - EVALUATING A RURAL MOTORIST INFORMATION AND DIVERSION SYSTEM

- APPLICABILITY: Comparison of variable message sign and Highway Advisory Radio effectiveness
- DOCUMENT AUTHOR(S), SOURCE, DATE: Wyoming State Highway Department (WSHWD), Traffic Operations Branch July 1, 1977
- DOCUMENT IDENTIFICATION NO. None

This report describes an evaluation procedure for a motorist information system employed on a section of I-80 in Southeast Wyoming. The system consists of two remotely controlled variable message signs and a highway advisory radio system. Supplementing this system are direct links to a weather station where visual range and wind speed information are available. The objective of the above system is to provide the motorist with accurate and current information on road conditions and to divert traffic in the event of road closure.

The evaluation was based on the analysis of data from three sources: a general questionnaire handed out to all motorists; a truck driver questionnaire distributed through the Wyoming Trucking Association; and Citizens Band radio interviews. This data was obtained during the winter of 1976-77. A statistical analysis was performed on this data to determine if significant systematic relationships existed among the various information sources.

Complete results of the study are presented. The major conclusion resulting from this study is that the variable message signs received an excellent rating by road users as a source of road and travel information while the highway radio system has not been favorably received. Also, as a result of this study, maximum wind gust for the Arlington and Elk Mountain areas are planned to be displayed on the variable message signs during the winter of 1977-78.

Section A6

SELECTED BIBLIOGRAPHY: SECONDARY LITERATURE

A6-1 INTRODUCTION

The following pages contain a listing of references considered to be of secondary importance. These references were not abstracted, but are listed herein for reference purposes only.

A6-2 GENERAL

These are references dealing with miscellaneous topics concerned with reduced visibility.

- Allen, M.J., Vision and Driving. Traffic Safety, September 1969
- Cahoon, Roger, Use of Rumple Stripe to Reduce Maintenance and Increase Driver Safety, Highway Research Board Special Report N107
- California Division of Highways, Development and Evaluation of Raised Traffic Lane Markers, 1953 to 1968. Final Report 3, 1968
- Coding, P.J., Weather and Road Accidents. Climatic Resources and Economic Activity, (England) 1974
- Farnshaw, K.B., Obstructions to Visibility, U.S. Dept. of Commerce, Environmental Research Labs, Final Report, June 1976
- Finch, D.M., Roadway Delineation With Curb Marker Lights, Highway Research Board Bulletin, No. 336, January, 1962
- Hulbert, S.F., Exploratory Work on the Problem of Reduced Visibility - Final Report, California Division of Highways, California University, Los Angeles, Final Report, June, 1966
- Joksch, H.C., A Critical Appraisal of the Applicability of Benefit Cost Analysis to Highway Safety, Center for the Environment and Man, Inc., Hartford, Connecticut, Final Report 1974
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- Middleton W.E.K., Vision Through the Atmosphere, University of Toronto Press, 1952

- Michigan University, Highway Safety Research Institute, Factors Influencing the Effectiveness of Automotive Rear Lighting Systems, Final Report, October 31, 1975

- Rosenhouse, L., When Color Can Save Your Life, Health, September 1971

- Soliday, S., Development and Preliminary Testing of a Driving Hazard Questionnaire, Perceptual and Motor Skills, Ammons and Ammons, Missoula, Montana, V41; N3, December 1975

- Transportation Research Views, Transportation Research Board, The Maine Facility - Instrumented Two-Lane Highway Generates Continuous Information on Driver Behavior, N57, December 1974

- Winter, W., Fog-Rain-Bad Visibility, Polizei Technik Verkehn, West Germany, V16, N11, November, 1971

A6-3 FOG

The following references contain information on reduced visibility and RVG systems in fog.

- Backwell, H.R., Roadway Illumination and Visibility in Fog, Illuminating Engineering Journal, October 1971

- Behrens, H., Lighting of Motor Vehicles in Fog, Karlsrue Technical University, West Germany, Illumination Institute, Final Report

- Brown, I.B., Study How Fog Fools Drivers, Traffic Safety, December 1971

- Codling, P.J., Thick Fog and Its Effect On Traffic Flow and Accidents, Road Research Laboratory (England), Final Report 1971

- Davey, J.B., Safe Driving in Fog, Ophthalmic Optician

- Finch, D.M., Highway Smoke Studies, Highway Research Board Proceedings, Vol. 28, December 1948

- Hisdal, B., Driving in Reduced Visibility Due To Adverse Weather, Central Institute for Industrial Research, Norway - Final Report

- Kloss, H., Automatic Fog Measurement Instrument, Federal Institute of Road Research (West Germany), Final Report, May 1974

- Laser Test Set for Fog Detection, Fleet Owner, New York, N.Y., December 1974

- Marsh, C.R., Efforts to Improve Visibility in Fog, Highway Research Bulletin, N191, 1958

- Michaelis, E.E., Fog Warning: A Step Towards Automation In Accident Prevention Roads and Road Construction, London, Vol. 49, No. 588, December 1971

- Selby, E., Fog - Nature's Gentle Strangler, Traffic Safety, February 1974

- Trani, C., Rear End Collision Prevention in Foggy Areas, Automobile Club of Milan, Italy, Department of Traffic Engineering, Final Report

A6-4 SNOW

The following references contain information on reduced visibility and RVG systems for hazardous conditions due to snow.

- Brown, R.J., Snow Studies (A Bibliography with Abstracts), National Technical Information Service, January 1975

- Norem, H., Snow Problems in Planning and Design of Mountain Highways, Technical University of Norway, Department of Road Technology, Final Report, July 1973

- Snelgrove, F., Colavincenzo, O., Snow Plow Visibility, Ontario Ministry of Transportation and Communications, Canada, Final Report, September 1975

- Wasserman, S.E., Monte, D.J., Relationship Between Snow Accumulation and Snow Intensity As Determined From Visibility, 29th Annual Eastern Snow Conference Proceedings, V17, February 5, 1972

A6-5 DUST

The following reference discusses driving difficulties due to dust.

- Ireland, B.F., Dust-Driving Problems - AHD's Answer, Arizona Conference Roads & Street Proceedings, April, 1972

A6-6 RAIN

The following references contain information on reduced visibility and RVG systems due to rain.

- Roalman, P., Rain On The Road, Family Safety, Fall, 1966
- Stanley, C.F., Wet Weather Driving Hazard: Hydroplaning, Safety Newsletter (National Safety Council), November 1968
- Tooke, W.R., Hurst, D.R., Wet Night Visibility Study (Roadway Markings) Report, Engineering Experiment Station, Georgia Institute of Technology, Final Report, July 1975

Section A7

LITERATURE REVIEW INDEX

A7-1 INTRODUCTION

This index contains lists of references identified by key words or phrases arranged alphabetically. Each reference number contains three characters representing the section number, paragraph number, and subparagraph letter, respectively. For example, the literature summary identified by reference number III8A is located in Section 3, paragraph 3-8a.

A7-2 ACCIDENTS

		Reference Number
a.	DUST	
•	Countermeasure Approaches:	V3A
•	Motorist Surveys:	V3A
•	Prediction:	V3A
•	Problem:	V3A
•	Rates:	V3A
b.	FOG	
•	Analysis:	II2B, III6C
•	Avoidance Techniques:	II2E
•	Countermeasure Approaches:	I3, II2A, III3E, III3G, III3J, III3L
•	Crash Injury Reductions:	III3D
•	Influence of Vehicle Maintenance:	III2E
•	Motorist Surveys:	II2C, III3K
•	Multiple Collisions:	II2C
•	Post Accident Control:	III3D

		Reference Number
•	Prediction:	III6B
•	Stopping Sight Distance:	I2A, III3G, III3H
•	Traffic Flow:	I3A, III2C, II2E, III3C, III3F, III3G, III3I, III6B, V2H
c.	RAIN	
•	Countermeasure Approaches:	II4B
•	Rates:	II4B
d.	SNOW	
•	Accident Frequency:	III5A

A7-3 ADVERSE WEATHER CONTROL TECHNIQUES

	Reference Number
• General (Fog, Dust, Snow, Rain, Smoke):	III2A

A7-4 CENTRAL DATA PROCESSING EQUIPMENT

	Reference Number
• Computers:	III3E, IV5A
• Logic Development for a Warning System:	III3E

A7-5 DELINEATION TREATMENTS

	Reference Number
• Colored Pavements:	III6C, III6H
• Cost/Benefit Analysis:	III6C, III6H
• Delineation Treatment:	III6A to III6H
• Economic Aspects	III6C, III6F, III6H
• Evaluation and Testing:	III6B, III6C, III6F, III6G

	Reference Number
• Future Research Needs:	III6F
• Glass Beads:	III6A
• Guidelines:	III6C, III6F
• Horizontal Road Markings:	III6C, III6F
• Lateral Placement:	III6B
• Literature Reviews:	III6C, III6H
• Median Visibility:	III6E
• Non-Snowplowable Markers:	III6C, III6G
• Post Delineators:	III6C, III6H
• Raised Pavement Markers:	III6A, III6C, III6D, III6F, III6H
• Rumble Strips:	III6C, III6H
• Rural Delineation:	III6B
• Thermoplastic Delineation:	III6A, III6C
• Traffic Paint:	III6A, III6C
• Traffic Performance Measures:	III6B, III6C

A7-6 DRIVING BEHAVIOR

	Reference Number
• Dust:	III2A, V3A
• Fog:	II2A, II2D, III2A, III2B, III3C, III3D, III3G, III3K, V2A, V2F
• Rain:	II4B, II4C, III2A
• Snow:	II3A, III2A

A7-7 ECONOMICS

	Reference Number
• Cost Benefit Analysis:	III2C, III3D, III3E, V5A (also see delineation treatments)
• Cost Effectiveness:	III3E
• Risk Analysis:	III2C

A7-8 EVALUATIONS

• Data Collection:	III3C, III3G, V2A, V2H, V2I, V3A, V5A
• Experimental Design:	III3C, III3G, V2A, V2B, V2G
• Fog Detectors:	V2I, V5A, IV2P

A7-9 GUIDANCE EQUIPMENT AND OTHER MOTORIST AIDS

	Reference Number
• User Survey	III3E
• Vehicle-Mounted Guidance Lights:	IV7A, IV7B
• Vehicle Rear Lighting:	III3J, III3D

A7-10 HANDBOOK DEVELOPMENT

	Reference Numbers
• Communications:	III2D

A7-11 INTERVEHICLE COMMUNICATIONS

	Reference Numbers
• Motorists:	III3B

A7-12 LITERATURE REVIEWS

	Reference Number
• Fog Problem and Systems:	III3A, III3C, III3E, III3G, III3I, III3M

A7-13 MOTORIST GUIDANCE

	Reference Number
• Clues and Traffic Control:	III2A, III2E, V2A
• Public Information:	III3B
• Techniques (General):	III3B, III3C, III3D, III3I

A7-14 MOTORIST GUIDANCE AND WARNING SYSTEMS

	Reference Number
• Dust:	V3A
• Evaluations:	V2A, V2B, V2C, V2E, V2H, V2I, V3A, V5A, V5B, V5C
• Fog:	V2A to V2I
• Functional Requirements:	III2A, III3I, V2G
• General:	I3B, III3F, III3G
• Recommended System Configurations:	V2G
• Snow:	None

A7-15 POLICE ENFORCEMENT AND OPERATING PROCEDURES

	Reference Number
• General:	III3B, III3D, IV2N, V5B, III3N

A7-16 REDUCED VISIBILITY

a. COUNTERMEASURES

	Reference Number
• Fog Dispersal:	II8A
• General:	III2A, III3A, III3B, III3C, III3E, III3G, III3I, III3L, III3M

b. DETECTION EQUIPMENT

• Dust Detectors:	None
• Evaluations:	III3E, III3G, IV2O

	Reference Number
• Fog Detectors:	IV2A to IV2K, IV2P
• General:	III3E, III3G, IV2L to IV2O, VA6, V2F
• Snow Detectors:	IV8A, IV8B

c. ENVIRONMENTS

1. Dust

	Reference Number
• Classification and Types:	I4A
• Mechanism and Behavior	I4A, V3A
• Prediction:	I4A

2. Fog

	Reference Number
• Abatement Techniques:	I3B, III3C, III3D
• Analysis (Highway):	III3G
• Classification:	I3C
• Effect on Visibility:	I3A, III2B, III3D, III3G, III3H
• Forecasting:	I3A, III3D, III3G
• General Theory:	I3C
• Incidence:	I3A
• Measurement and Index Development:	III3G
• Modeling and Simulation:	III3G
• Nighttime Fog:	III3H, V2A
• Visibility Determination:	I2A
• Visibility Standards:	V2A

3. RAIN

	Reference Number
• Passing Sight Distance:	I6A
• Simulation:	II4C
• Traffic Control:	I6A
• Visibility Degradation:	I6A, II4C

4. Snow

	Reference Number
• Countermeasures:	III5B
• Modeling Techniques:	III5A, III5B
• Nature and Formation:	III5B
• Research Needs:	III5B, III5C
• Snow Fences (Mechanics & Placement):	III5A, III5C, III5D
• Snow Drift Control:	III5C, III5D
• Test Results-Snow Fences	III5D
• Windspeed/Snow:	III5A
• Wind Tunnel Studies:	1115B
• Visual Range:	III5A

A7-17 ROADWAY LIGHTING TECHNIQUES

	Reference Number
• Evaluation:	V2B, V2H, V2J
• Techniques:	III2B, V2B, V2H

A7-18 SIGNING

	Reference Number
• Audio Signing (Roadside Radio):	III7A, III7B, III7C
• Brightness and Legibility:	IV4B
• Design Guidelines:	IV4B, V2F
• Evaluation:	III3N, IV4A, V2A, V2C, V2E, V3A
• Study Design:	IV4A
• User Survey:	III3E

	Reference Number
• Warning Signs:	III3E, III3F, V2C, V2E, V2F, V2G, V3A, V5B
• VMS State of Art:	IV4C

A7-19 VEHICLE DETECTORS

	Reference Number
• Application:	V2C, V2E, V2F
• Reliability:	IV3A

Appendix B
TYPICAL DATA REQUIREMENTS FOR SYSTEM EVALUATION (ARIZONA SYSTEM)

B1 INTRODUCTION

This appendix describes the type of data requested of the sample system agencies for performing the evaluation analysis. The data requirements for the Arizona System is presented for the purpose of illustrating a typical situation.

B2 DATA REQUIREMENTS (ARIZONA)

a. WEATHER AND REDUCED VISIBILITY DATA

1. Type and nature of dust problem
2. Frequency and location of major dust storm activity
3. Frequency and location of localized dust storm activity
4. Identification of dust storm activity (major and localized) related to RV accidents
5. Identification of media RV warnings prior to RV incidents
6. Identification of dust storm detection procedures
7. User assessment of RV problem

b. ACCIDENT DATA

1. Total - all accidents
2. RV (dust related) accidents (before and after)
3. Number of multiple car collisions
4. Cost estimates of RV accidents
5. Number of RV accident fatalities
6. Number of RV accident injuries

7. Identification of time of day when accident problem is most prevalent

8. RV accident; vehicles vs. trucks; local vs. out-of-state drivers

c. ROADWAY GEOMETRICS

1. Location and length of roadway sections under study

2. Number of lanes

3. Roadway curvature and grades

4. Type of shoulder and median area:

- Width of shoulder and median

5. Location of interchanges, exit and entrance ramps

6. Identification of areas adjacent to roadway:

- Cut, fill or level sections
- Roadside vegetation or land classification

d. ROADWAY OPERATION DATA

1. Roadway AADT's; percentage of truck traffic

2. Traffic flow mix (local, intrastate and out-of-state drivers)

3. Traffic peaking characteristics

4. Changeable message sign usage for RV (dust) warnings

5. State police patrolling frequency

6. Identification of operational procedures between State personnel and police

e. SYSTEM EQUIPMENT

1. Changeable Message Signs

(a) Location of signs and identification of rationale used for sign placement

(b) Operational characteristics and capability of signs:

- Type and number of messages

- Equipment operation
- Complexity of equipment

(c) Identification of events leading to the display of RV messages

(d) Date signs became operational

(e) User assessment of sign reliability and maintainability

(f) Capital, operational, and maintenance costs

2. Radio-Control Communications Equipment

(a) Type, function and capability of equipment used (field and central)

(b) User assessment of equipment reliability and maintainability

(c) Capital and maintenance costs

3. Roadway Delineation Treatments

(a) Type of treatments used

(b) User assessment of treatment effectiveness

f. CONTROL CENTER OPERATION

1. Identification of Control Center Equipment

(a) Type and function

(b) Operational capability

(c) Reliability and maintainability of equipment

2. Identification of System Operational Procedures

(a) Events leading to changeable message sign activations

(b) Interface function with State field personnel and State Police

(c) Hierarchy of decision process

3. State Assessment of System Operating Complexity

g. PUBLIC REACTION

1. Motorist Surveys (If Any)

(a) Credibility of system

(b) Sign effectiveness

(c) Overall reaction

2. Field Observations of Traffic During RV Environment (If Any)

(a) Vehicle speed and visibility measurements when signs are activated

3. Media Coverage of RV (Dust) Problem

(a) Local newspaper coverage of RV accidents

(b) Local newspaper opinion of system (possibly editorials)

(c) Local TV and radio station opinion on system

(d) Coordination process used between State and media to disseminate information on RV to the public

(e) Identification of information programs used

4. Direct Motorist Reaction

(a) Type and number of letters sent to State expressing an opinion of the system

h. HISTORY OF SYSTEM

1. Identification of Chronological Events Leading to System Installations

i. SYSTEM COSTS

1. Overall System Costs - Capital, Operational and Maintenance

j. SYSTEM EVALUATION REPORTS (IF ANY)

1. Formal or Informal

k. USE OF SYSTEM EQUIPMENT AND/OR PERSONNEL FOR OTHER PURPOSES.

Appendix C
SPECIAL FEATURES EVALUATION STUDIES
INTRODUCTION

At the beginning of the study, it appeared that certain systems had special features that lent themselves to experiments which might in turn, lead to some useful comparison data.

This was the case, for example, in the Oregon system, where vehicle detectors in the roadway and hard copy detector output data offered the possibility of correlating vehicle speeds with visibility conditions and variable sign messages to draw some conclusions concerning the effectiveness of speed signing in real fog conditions.

A similar possibility presented itself on the New Jersey Turnpike, where there appeared to be considerable data available in the form of hard copy vehicle detector outputs and message displays. There were also recorded conversations between the state troopers and the central facility during the course of which visibility ranges were discussed. The New Jersey Turnpike also made use of both bulb matrix and neon message signs, which might be used to make visibility comparisons under various fog conditions.

This appendix discusses the approach to each of these investigations and the results which were achieved. Appendix C-1 deals with the analysis of the effectiveness of the Oregon variable message signs. Appendix C-2 discusses the New Jersey Turnpike bulb matrix - neon tube message sign comparison. Appendix C-3 is a discussion of the attempt to establish the relation of New Jersey Turnpike variable message signing to driven behavior through observation of vehicle detector speeds.

Appendix C-1

SPECIAL FEATURES EVALUATION
OREGON SIGN EFFECTIVENESS ANALYSIS

C1-1 INTRODUCTION

This appendix represents the results of the analyses performed to investigate the effectiveness of variable message signing in controlling traffic on a six mile (9.7 Km) section of Interstate 5 near Albany, Oregon during periods of reduced visibility due to fog. The study focused on the six variable message signs along I-5 which are part of the Oregon RVG system.

C1-2 OBJECTIVES

The basic objective of the study was to examine the impact of variable message signing on driver behavior during fog conditions. The specific objectives were to:

- Determine effect of speed signing (posting an advisory).
- Determine whether driver behavior shows evidence of modification during fog as a result of signing: are the means speeds lower in fog even where no signs visible?
- Examine speed variance patterns to determine differences when signs are visible and not visible.

C1-3 SYSTEM DESCRIPTION

The six variable message signs (3 northbound and 3 southbound) are spaced from one to two miles (1.6 to 3.2 Km) apart along a six mile (9.7 Km) section of Interstate 5, which is a two lane divided highway. These signs have the capability of displaying both a hazard warning message and an advisory speed. The signs can display any advisory speed from 10 to 50 mph (16.1 to 80.5 kph) in increments of 10 mph (16.1 kph). Control of the signs is exercised from the State Police office located at the southern end of the system. Associated with the variable message signs is a series of twenty inductive detector speed traps, one per lane just before each sign site and at both ends of the fog area. A minicomputer is used with the loop detectors to derive speed and headway data. Figure C-1 shows the relative locations of the variable message signs and loop detectors along the six mile (9.7 Km) section of Interstate 5.

The Oregon RVG system offers the possibility of performing an evaluation of sign effectiveness. Since the system is detectorized, driver behavior can be recorded and analyzed. Hard copy of speed and headway data for each detector site is available from the system teleprinter. The detectors at the beginning of the system

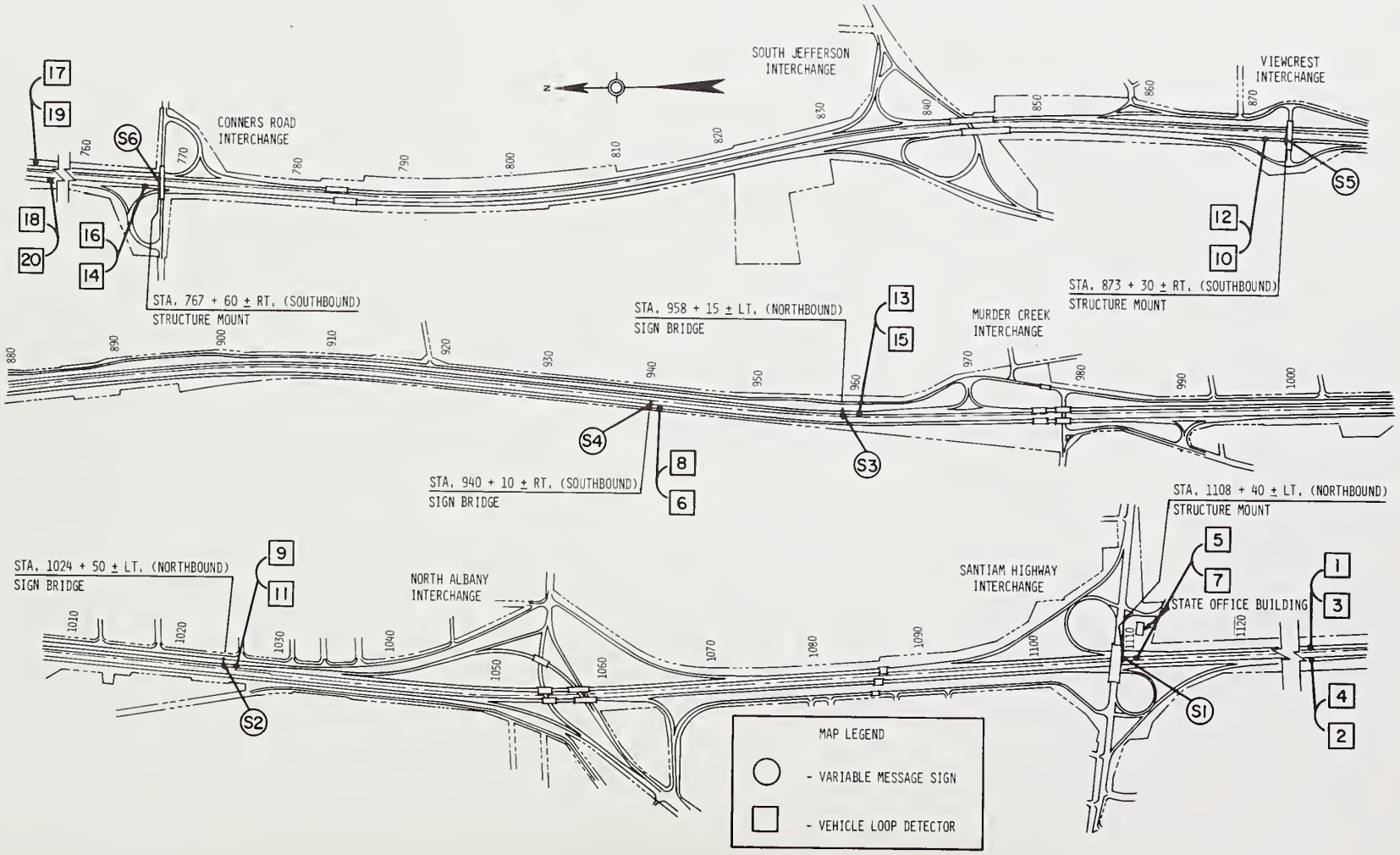

Figure C-1. Variable Message Sign and Loop Detector Locations on Oregon I-5 RVG System

are positioned in advance of the signs, well out of sight, but still within the fog area so that they can be used for comparison with detectors upstream and downstream of the signs.

C1-4 ANALYSIS APPROACH

The first step in the analysis was to select a common time period in which baseline traffic data (no fog condition) can be compared to data collected during a fog condition. The baseline data is also useful in identifying traffic flow patterns and operational problems with the system detectors.

Once the common time period was established, the vehicle mean speeds and speed variances were computed at the following detector sites: entry points of system, just in advance of signs, and somewhat downstream of the sign corresponding to detector numbers 1, 5, and 13 in the northbound direction 18, 14 and 10 in the southbound direction (Figure C-1). Hard copy printout of vehicle speeds provided by the system teleprinter served as the starting point for the analysis. A sample printout of these data is shown in Figure C-2.

Note that the printout provides only the number of vehicles within a speed "window" of 10 mph (16.1 kph) as a function of vehicle headways. Thus, the mean value of the vehicle speeds within a 15 minute time period cannot be computed unless some assumption is made about the distribution of speeds within the 10 mph (16.1 kph) window. For the data analysis, an assumption was made that the mean speed of a group of vehicles listed as having speeds between V and $V + \Delta V$ is $(V + \Delta V/2)$ mph. For example, the mean speed of the 40 mph (64.4 kph) to the 50 mph (80.5 kph) grouping, using this assumption, is 45 mph (72.4 kph).

The analysis of sign effectiveness was based on the detector data output obtained during the following time periods:

a. BASELINE DATA (NO FOG)

- Dec. 17, 1976: 1:25 AM to 3:10 AM (both directions)
- Dec. 17, 1976: 7:10 AM to 10:40 AM (both directions)

b. FOG CONDITION DATA

- Dec. 15, 1972: 1:27 AM to 2:27 AM (northbound detectors)
- Dec. 15, 1972: 1:42 AM to 3:12 AM (southbound detectors)
- Feb. 1, 1976: 7:17 AM to 10:47 AM (northbound detectors)
- Feb. 2, 1976: 7:17 AM to 10:47 AM (southbound detectors)

Only detectors in the shoulder lane, namely, detectors 1, 5, and 13 northbound and detectors 18, 14, and 10 southbound, were used in the analysis, because the median lane exhibited relatively low traffic volumes.

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ØØ  Ø3  ØØØØ  ØØØØ  ØØØØ  ØØØØ  ØØØ3  ØØØØ  ØØØØ  ØØØ3
ØØ  Ø4  ØØØØ  ØØØØ  ØØØØ  ØØØ1  ØØØ2  ØØØØ  ØØØØ  ØØØ4
ØØ  Ø5  ØØØ2  ØØØØ  ØØØØ  ØØØ2  ØØØ5  ØØØØ  ØØØØ  ØØØ9
ØØ  Ø6  ØØØØ  ØØØØ  ØØØØ  ØØØØ  ØØØ3  ØØØ1  ØØØØ  ØØØ4
ØØ  Ø7  ØØØØ  ØØØØ  ØØØØ  ØØØ1  ØØØ3  ØØØØ  ØØØØ  ØØØ4
ØØ  Ø8  ØØØØ  ØØØØ  ØØØØ  ØØØØ  ØØØ1  ØØØØ  ØØØØ  ØØØ1
ØØ  Ø9  ØØØØ  ØØØØ  ØØØØ  ØØØ2  ØØØ3  ØØØØ  ØØØØ  ØØØ5
Ø5  ØØ  ØØØ3  ØØØØ  ØØØØ  ØØØ2  ØØ24  ØØØØ  ØØØØ  ØØ29

 TOTAL  ØØØ6  ØØØØ  ØØØØ  ØØØ9  ØØ52  ØØØ1  ØØØØ  ØØ68


Ø5:  46:  ØØ  PM  11/  16/  76
                              SPEED HEADWAY REPORT
                                INTERVAL   ØØ15
                                DETECTOR   ØØ14
          ----SPEED IN MPH----
HEADWAY   2Ø    3Ø    4Ø    5Ø    6Ø    7Ø    7Ø+   TOTAL
ØØ  Ø1  ØØØØ  ØØØ1  ØØØØ  ØØØ6  ØØØ4  ØØØØ  ØØØØ  ØØ11
ØØ  Ø2  ØØØ1  ØØØØ  ØØØ1  ØØØ8  ØØØ5  ØØØØ  ØØØØ  ØØ15
ØØ  Ø3  ØØØ1  ØØØØ  ØØØ1  ØØØ4  ØØØ9  ØØØØ  ØØØØ  ØØ15
ØØ  Ø4  ØØØØ  ØØØ1  ØØØØ  ØØØ5  ØØØ6  ØØØØ  ØØØØ  ØØ13
ØØ  Ø5  ØØØØ  ØØØØ  ØØØØ  ØØØ2  ØØØ9  ØØØØ  ØØØØ  ØØ11
ØØ  Ø6  ØØØØ  ØØØØ  ØØØØ  ØØØ2  ØØØ8  ØØØØ  ØØØØ  ØØ18
ØØ  Ø7  ØØØØ  ØØØØ  ØØØØ  ØØØ6  ØØØ1  ØØØ1  ØØØØ  ØØØ8
ØØ  Ø8  ØØØØ  ØØØØ  ØØØØ  ØØØ3  ØØØ4  ØØØØ  ØØØØ  ØØØ7
ØØ  Ø9  ØØØØ  ØØØØ  ØØØØ  ØØØ1  ØØØ3  ØØØØ  ØØØØ  ØØØ4
Ø5  ØØ  ØØØØ  ØØØ1  ØØØØ  ØØ12  ØØ17  ØØØ1  ØØØØ  ØØ31

 TOTAL  ØØØ2  ØØØ3  ØØØ2  ØØ5Ø  ØØ66  ØØØ2  ØØØØ  Ø125


Ø5:  46:  ØØ  PM  11/  16/  76
                              SPEED HEADWAY REPORT
                                INTERVAL   ØØ15
                                DETECTOR   ØØ16
          ----SPEED IN MPH----
HEADWAY   2Ø    3Ø    4Ø    5Ø    6Ø    7Ø    7Ø+   TOTAL
ØØ  Ø1  ØØØ1  ØØØØ  ØØØØ  ØØØ1  ØØØ5  ØØØØ  ØØØØ  ØØØ7
ØØ  Ø2  ØØØØ  ØØØØ  ØØØØ  ØØØØ  ØØØ6  ØØØØ  ØØØØ  ØØØ6
ØØ  Ø3  ØØØØ  ØØØØ  ØØØØ  ØØØ1  ØØØ1  ØØØØ  ØØØØ  ØØØØ
ØØ  Ø4  ØØØØ  ØØØØ  ØØØØ  ØØØ1  ØØØ4  ØØØ1  ØØØØ  ØØØ6
ØØ  Ø5  ØØØØ  ØØØØ  ØØØØ  ØØØØ  ØØØ2  ØØØØ  ØØØØ  ØØØ2
ØØ  Ø6  ØØØØ  ØØØØ  ØØØØ  ØØØØ  ØØØ4  ØØØØ  ØØØØ  ØØØ4
ØØ  Ø7  ØØØØ  ØØØØ  ØØØ1  ØØØØ  ØØØ2  ØØØØ  ØØØØ  ØØØ3
ØØ  Ø8  ØØØØ  ØØØØ  ØØØØ  ØØØ1  ØØØ2  ØØØ1  ØØØØ  ØØØ4
ØØ  Ø9  ØØØØ  ØØØØ  ØØØØ  ØØØ1  ØØØ3  ØØØØ  ØØØØ  ØØØ4
Ø5  ØØ  ØØØ2  ØØØØ  ØØØØ  ØØØ3  ØØ18  ØØØ1  ØØØØ  ØØ24

 TOTAL  ØØØ3  ØØØØ  ØØØ1  ØØØ8  ØØ47  ØØØ3  ØØØØ  ØØ62

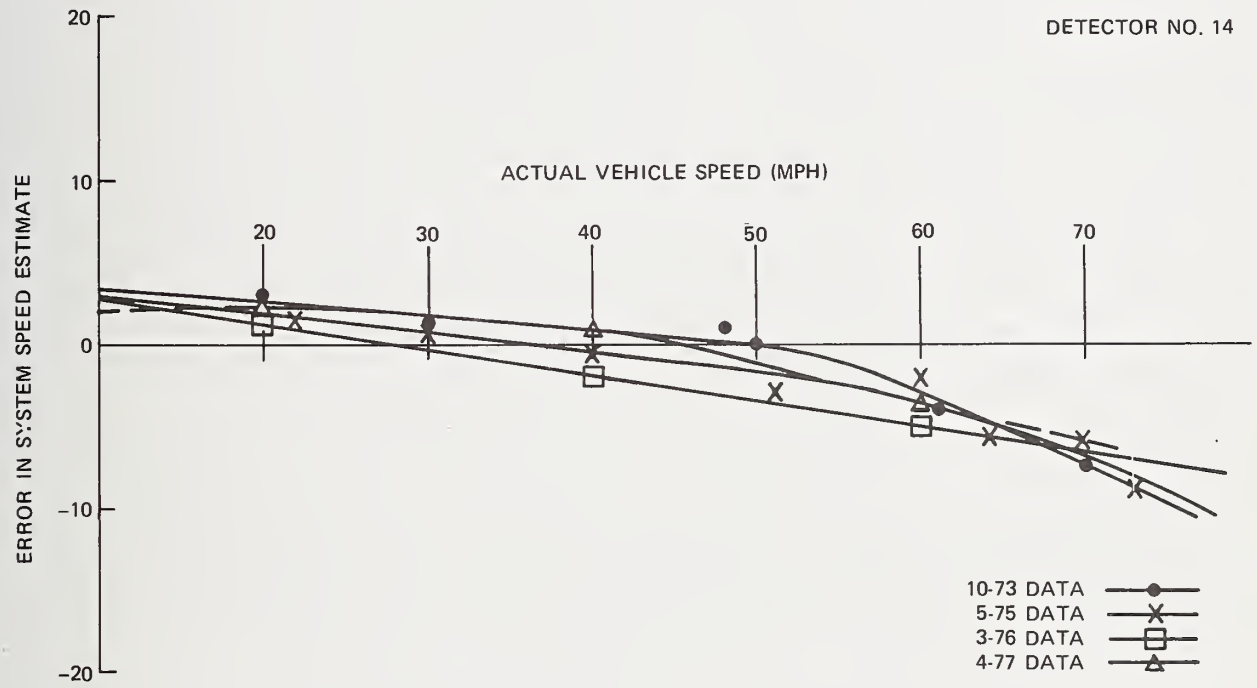

Ø5:  46:  ØØ  PM  11/  16/  76
                              SPEED HEADWAY REPORT
                                INTERVAL   ØØ15
                                DETECTOR   ØØ18
          ----SPEED IN MPH----
HEADWAY   2Ø    3Ø    4Ø    5Ø    6Ø    7Ø    7Ø+   TOTAL
ØØ  Ø1  ØØØØ  ØØØØ  ØØØØ  ØØØ1  ØØØ2  ØØØØ  ØØØØ  ØØØ3
ØØ  Ø2  ØØØØ  ØØØØ  ØØØØ  ØØØ4  ØØ11  ØØØØ  ØØØØ  ØØ15

NOTE:  1 MPH = 1.609 KPH
```

Figure C-2. Oregon Research System Printout

During the course of the analysis, it was learned that the system detectors exhibit a drift error, whose cause is as yet unknown, which results in a erroneous speed computation. The error varies considerably over a long period of time and is different for each detector. Oregon DOT personnel provided calibration data which was obtained by making runs over each detector at known speeds and observing computer speeds. A sample of the calibration data is shown in Figure C-3. Using calibration data for the detectors in this analysis, corrected values of the hard copy printout speeds were computed, as shown in Table C-1. This was done by averaging the detector drift errors over time.

When mean speeds and variances had been computed for the fog and no-fog conditions, they were plotted to make comparisons easier, as shown in Figures C-4 and C-5.



NOTE: 1 mph = 1.609 kph

Figure C-3. Typical Detector Calibration Curves

TABLE C-1. CALIBRATED DETECTOR SPEEDS

Det. No.	System Speed (mph)	Calibrated Speed (mph)	Det. No.	System Speed (mph)	Calibrated Speed (mph)
18	10	7	1	10	8
	25	23		25	22
	35	34		35	31
	45	45		45	42
	55	56		55	53
	65	68		65	64
	75	80		75	75
14	10	8	5	10	9
	25	24		25	26
	35	35		35	37
	45	46		45	49
	55	57		55	63
	65	71		65	76
	75	83		75	86
10	10	8	13	10	7
	25	24		25	22
	35	34		35	32
	45	44		45	42
	55	55		55	54
	65	67		65	66
	75	79		75	79

NOTE: 1 mph = 1.609 kph

C1-5 RESULTS AND CONCLUSIONS

The late morning means and standard deviation of the vehicle speeds for the detector sites under study are summarized in Figures C-4 and C-5[1], respectively. The prevailing visibility conditions and advisory speeds displayed during the late

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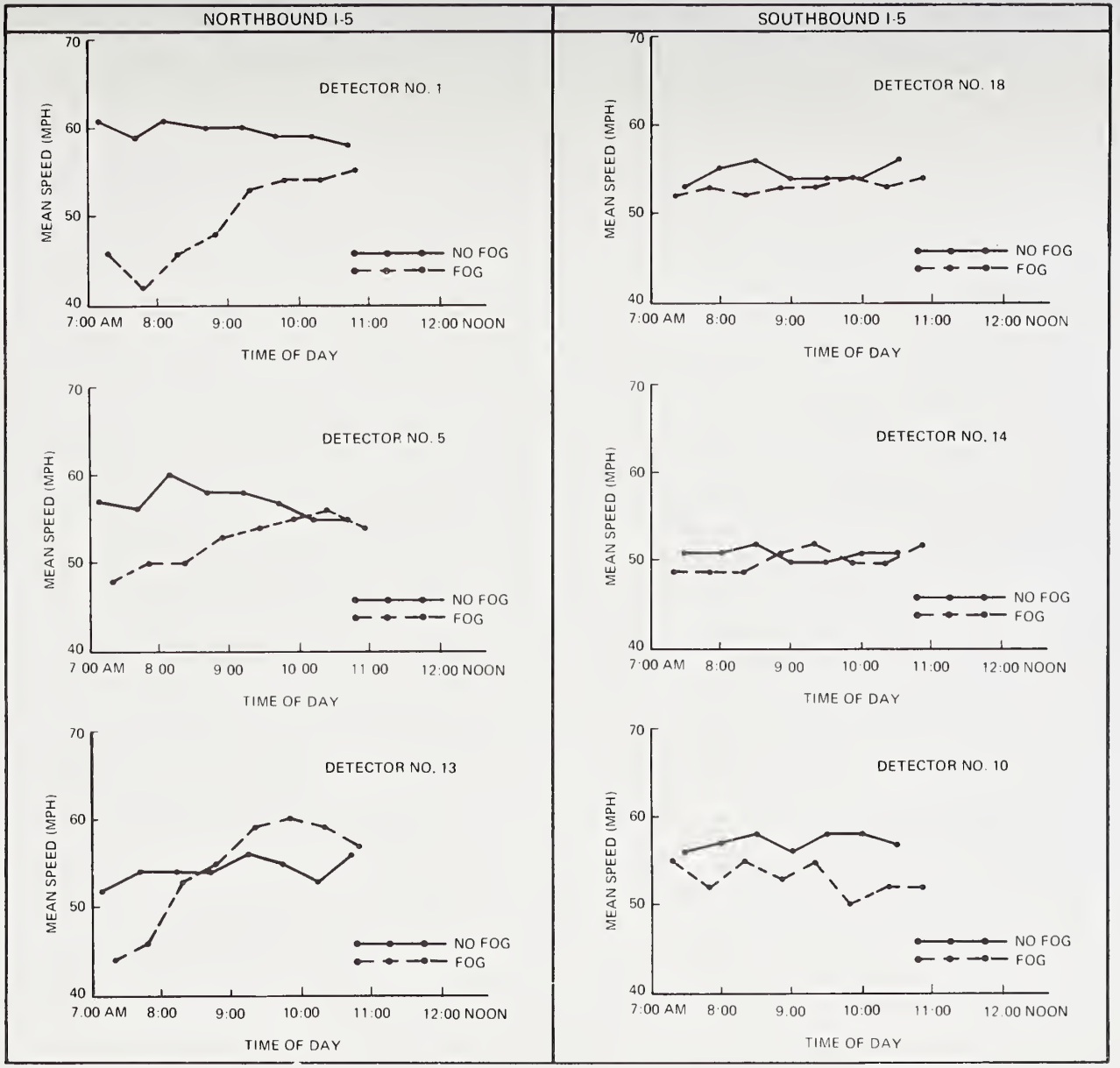
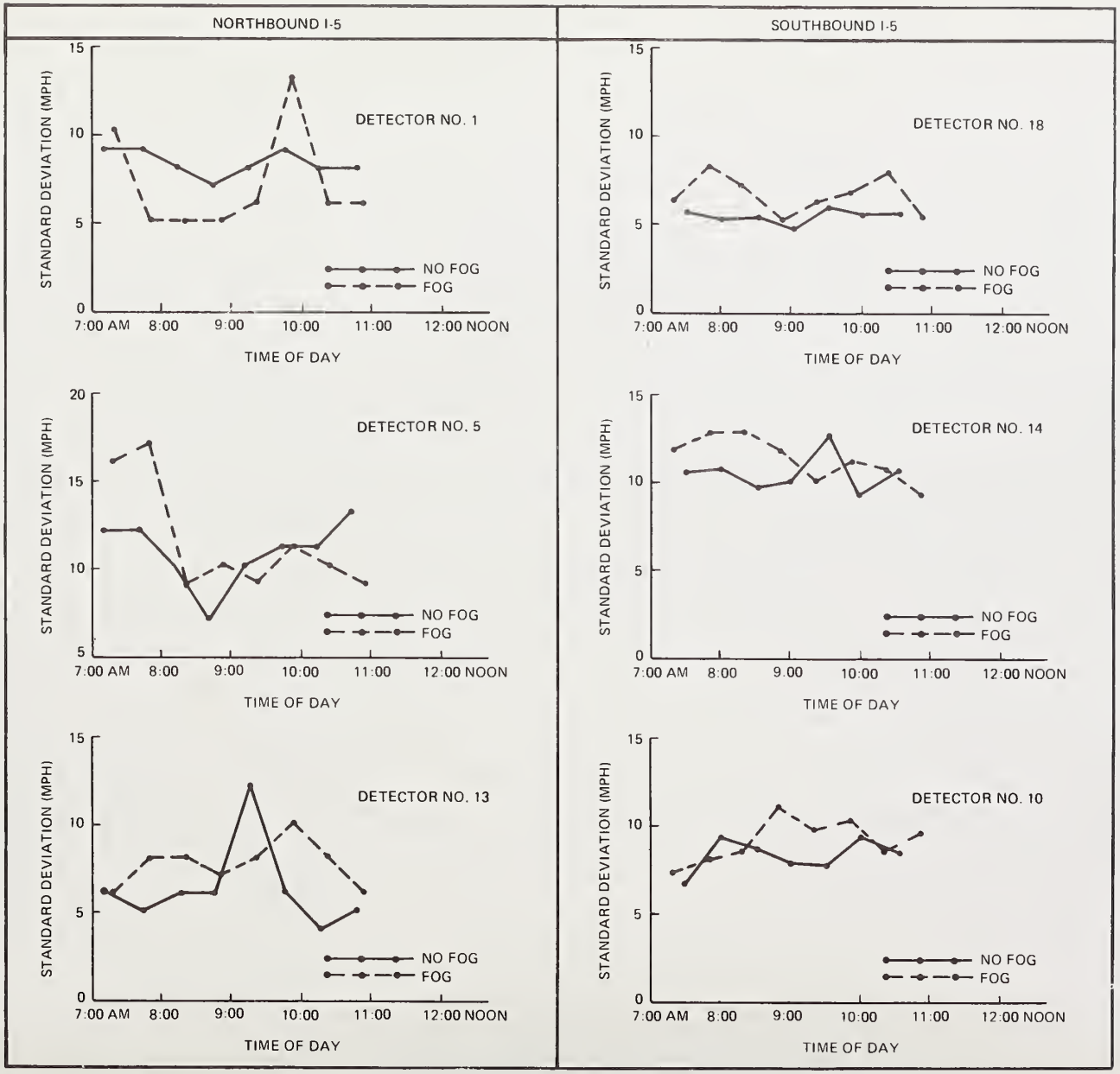
[1]The number of vehicles in the early morning sample of speed data was to small to yield means and variances of any significance. Figures C-4 and C-5, therefore, exhibit only the comparison between late morning no-fog and late morning fog conditions.



NOTE:

1 mph = 1.609 kph

Figure C-4. Comparison Between Fog and No-Fog Mean Speeds



NOTE: 1 mph = 1.609 kph

Figure C-5. Comparison Between Fog and No-Fog Speed Standard Deviations

morning time period are described in Table C-2. Observations pertaining to late morning data are as follows:

a. NORTHBOUND

- Mean speeds are lower in fog when compared to the non-fog condition at all detector locations, including the advance detector which is out of sight of the first sign.
- Mean speeds in fog decrease at the beginning of the fog period and then begin to rise, more or less independently of the posted speed.
- In some cases, vehicle speeds in fog appear to be greater than base-line speeds.
- Standard deviations of vehicle speeds show no particular trend; there does not appear to be any significant increase in the speed spread in fog as compared to the non-fog condition.

TABLE C-2. PREVAILING VISIBILITY CONDITIONS AND SIGN ACTIVATION DURING DATA ACQUISITION

	Direction	
	Northbound	Southbound
Detector Number Data Acquisition Date	1, 5, and 13 DEC. 15, 1972 and FEB. 1, 1976	18, 14, and 10 DEC. 15, 1972 and FEB. 2, 1976
Events*	• 1:11 AM; visibility ≅ 300 ft. All signs set at 30 mph.	• 1:11 AM; visibility ≅ 300 ft. All signs set at 30 mph.
	• 3:22 AM; visibility improved. All signs set at 50 mph.	• 3:22 AM; visibility improved. All signs set at 50 mph.
	• 3:59 AM; all signs set at 40 mph.	• 6:44 AM; all signs set at 40 mph.
	• 11:17 AM; all signs turn off.	• 11:32 AM; all signs turn off.

NOTE: 1 mph = 1.609 kph
*Events described relate to Figures C-4 and C-5.

b. SOUTHBOUND

- Mean speeds in fog seem not to be significantly different from those not in fog; the same could be said for the standard deviations.

C1-6 OVERALL CONCLUSIONS

The presence of fog itself seems to have at least as much effect as the signs themselves (based on the comparison of advanced detector speeds (Number 1 northbound and Number 18 southbound) with speeds over detectors near and after signs.

There is no evidence to suggest that there is any change in speed "spread" when fog occurs; however, the conclusions must be qualified by the fact that:

- Granularity of the speed data prevents good estimates of mean speeds.
- Detector calibrations are averages over a long period. The actual error on the day of the data acquisition would be better.
- Fog conditions at the individual detector sites may vary from minute to minute, and may not have any relation to the visibility which police patrol personnel estimate when they change posted speeds. This may be the reason for the observed increase in mean speeds following the initial decrease after the reduced speed advisory message was posted. It may also be the reason for the differences between the observed northbound effects as compared to southbound.

Appendix C-2

SPECIAL FEATURES EVALUATION NEW JERSEY TURNPIKE VARIABLE MESSAGE SIGN COMPARISON

C2-1 INTRODUCTION

The New Jersey Turnpike uses several different types of variable message signs. Two of particular interest are the speed warning signs, which use neon tubing, and the speed limit signs which are a combination type employing neon tubing to display the normal speed limits, and a bulb matrix used to indicate reduced speed limits. Figures C-6 and C-7 indicate the construction of these signs. The speed limit sign presents an opportunity to make a comparison of the readability of neon vs. bulb matrix signs under reduced visibility condition.

A series of measurements were made of two of the speed limit signs under clear conditions using a Pritchard photometer; one of the signs showing the normal speed limit with the neon tubing, and the other showing a reduced speed limit (for a construction zone) using the matrix bulbs.

Originally it was intended to take further measurements and photographs under reduced visibility conditions at the northern terminus of the Turnpike. However, during this period of the study, despite several trips to the affected area where fog seemed to be impending, no fog was found of sufficient density to make meaningful measurements possible. Therefore, it was decided to make comparisons between the two signs based on the clear weather measurements and an analytic approach.

C2-2 MEASUREMENTS IN THE CLEAR

Measurements were taken of the brightness of several different background areas of the signs, and a sequence of measurements was taken vertically across the illuminated numeral. The background areas of the neon illuminated sign was measured to be about 20 ft. lamberts. The background areas of the matrix sign measured between 0.5 and 1.0 ft. lambert. The difference is attributable primarily to the differences in the general illumination level at the time of the measurement, and sign location. The measurements were made on an overcast day, and the measurements on the matrix sign were made later in the day. The sky brightness at the time of the measurements on the matrix sign measurement was 185 ft. lamberts.

The spot size of the Pritchard photometer used was 6 minutes of arc. The measurements were taken from slant range distances of 65 and 108 feet (19.8 and 32.9m) for the neon sign, and 65 feet (19.8m) for the matrix sign. The spot diameter corresponding to these distances is about 1.36 inch (3.45 cm) and 2.26 inches (5.74 cm) respectively. The neon tubing is standard 15 mm diameter, and the matrix bulbs are 30 watt, R-20 reflector bulbs, which have a diameter of about 2.5 inches (6.35 cm).

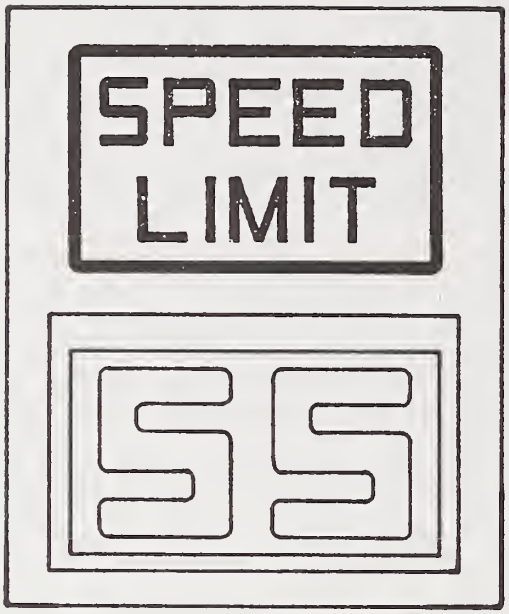


Figure C-6. Neon-Bulb Matrix Speed Limit Sign

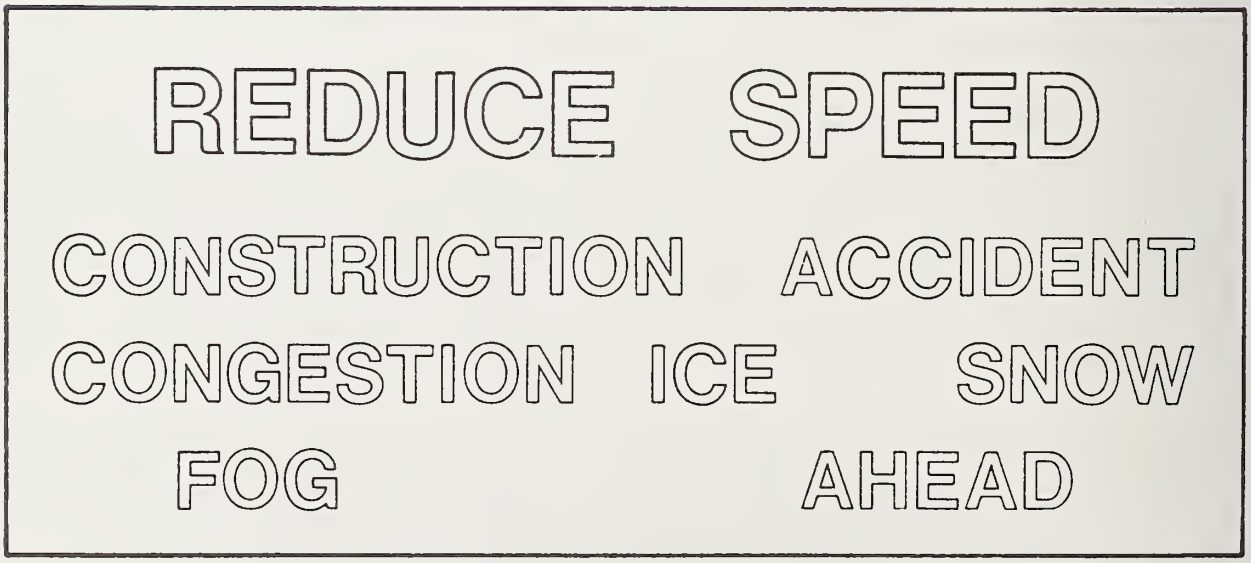


Figure C-7. Neon Speed Warning Sign

Compensating for the fact that the neon tubing did not cover the entire spot size, a neon brightness of 420 ft. lamberts was calculated. This agrees reasonably well with the value of 0.16 cd/cm^2 (equivalent to 467 ft. lamberts) given in the IES handbook (Reference 2) for neon tubing, particularly when allowances are made for dirt, etc. The maximum measured brightness of a matrix bulb was 2435 ft. lamberts. This is considerably lower than the brightness calculated from the 290 cd given in the IES Lighting Handbook for a 30-watt R-20 bulb in the central 10°, even with spot correction.

Part of the difference can be accounted for by the fact that the bulbs are operated at a reduced voltage (97V compared to 115V nominal) after dusk, because of glare complaints. This results in a reduction of $(97/115)^{3.4} = 0.56$ in the rated brightness (Reference 2, page 8-7). In addition, some loss of brightness is due to age and to dirt accumulation on the bulb surface.

C2-3 CALCULATED VISIBILITY IN FOG

The visibility of the neon and the matrix signs are calculated for two cases: daylight, and night in the presence of the vehicle headlights. In both cases, the analyses are similar to, and use results and data from the NCHRP study on Highway Fog (Reference 3).

C2-4 DAYLIGHT SIGN VISIBILITY

The visibility of the sign is related to the contrast ratio of the numeral to its background. Equation A-3 of Reference 3 is relevant to this case:

$$C = \frac{B_o - B_b}{B_b} = \frac{B_o^* - B_b^*}{B_b^* + B_h(e^{sr} - 1)}$$

where:

C = the contrast ratio

B_o = the brightness of the "object" numeral at the observer

B_b = the brightness of the background at the observer

B_h = the brightness of the "horizon sky"

s = the fog density "extinction coefficient"

r = the distance from the observer to the sign

ϵ = a constant, the base of natural logarithms

B_o^* = the brightness of the "object" numeral at the sign

B_b^* = the brightness of the background at the sign

Equating the contrast ratio, C, to a contrast ratio visibility threshold, ϵ, and solving for maximum visibility range, R, gives:

$$R = \frac{1}{S} \times \log_e \left| \frac{B_o^*(1 - \epsilon) - B_b^*}{B_h \epsilon} \right| + 1$$

In the classical definition of visibility the "object" is taken to be black, against the horizon sky, and the contrast ratio is equated to a threshold value of $\epsilon_d = 0.02$ which leads to equation A-5 of Reference 3 relating visibility to the extinction coefficient:

$$V = 3.912/s ,$$

where V is visibility range.

For highway visibility usage, a contrast detection threshold of $\epsilon_d = 0.02$ was believed to be somewhat optimistic for many usages, and a value of $\epsilon_d = 0.06$ was suggested as being more suitable. The latter value leads to $V = 2.81/s$ as the relationship between visibility and extinction coefficient. The best value to use in practice for relating visibility to the extinction coefficient, s, depends on the procedures used to measure the "visibility" by the particular operating authority. In the absence of better information, $\epsilon_d = 0.06$ will be used. Where character recognition is involved, as is the case of warning signs, it is believed that an even higher threshold contrast ratio is warranted, and a value of $\epsilon_d = 0.1$ has been used.

The "horizon" brightness in daytime fogs can vary over a large range. The IES Lighting Handbook (loc cit) gives a range for daytime fog brightness from 100 ft. lamberts to 5000 ft. lamberts. The latter case is a very bright fog which most people find quite uncomfortable. It occurs when the sun shines directly on a relatively shallow fog bank. The lower brightness levels are typical of fog with a heavy covering cloud layer. Even lower levels can, of course, be encountered at dawn and dusk.

Table C-3 gives calculated visibility range for both the neon and matrix signs using the above parameters.

C2-5 NIGHT SIGN VISIBILITY

This analysis considers only the backscatter from the vehicle as the predominant source of background veiling illumination. Where a high level of illumination from roadway luminaires is present, it can be treated as daylight fog if it is significantly higher than the headlamp backscatter. Otherwise, the resulting luminance can be added to the headlight backscatter.

Headlamp backscatter was included as a part of the models developed for the NCHRP study (Reference 2). The background brightness is a function of the

TABLE C-3. SIGN DAYLIGHT VISIBILITY

Fog Density		Sign Visibility Range - Feet (Meters)					
		Neon			Bulb Matrix		
Visibility Feet (meters)	Extinction Coefficient	100 Ft. Lamberts	1000 Ft. Lamberts	5000 Ft. Lamberts	100 Ft. Lamberts	1000 Ft. Lamberts	5000 Ft. Lamberts
50 (15.3)	.0563	64 (19.5)	23 (7.0)	10 (3.1)	96 (29.3)	55 (16.8)	30 (9.2)
100 (30.5)	.0281	128 (39.0)	45 (13.7)	19 (5.8)	191 (58.3)	110 (33.6)	60 (18.3)
200 (61.0)	.0141	257 (78.9)	91 (27.8)	38 (11.6)	383 (116.8)	219 (66.8)	119 (36.3)
500 (152.5)	.00563	642 (195.8)	227 (69.2)	96 (29.3)	957 (291.2)	548 (167.1)	298 (90.9)
1000 (305.0)	.00281	1283 (391.3)	454 (138.5)	192 (58.6)	1914 (584)	1095 (334)	596 (181.8)

relative geometry of the driver and the headlamp, the headlamp tilt, and the angle of the line-of-sight from the driver to the sign, as well as the fog density. The headlight brightness data used is from the NCHRP study, with a headlight tilt of zero, and a horizontal line-of-sight. The geometry used is representative of passenger vehicles. The actual line-of-sight is normally above the horizontal; however, the illumination of the headlamps drops with increasing elevation above the horizontal, so that the results will be conservative.

The brightness of the sign numeral at the viewing point is simply the numeral brightness attenuated by fog, plus the headlamp backscatter brightness. The background brightness is that produced by the headlamp backscatter. The sign background is sufficiently dark, so that the illumination from the headlight will have negligible effect for fog levels of interest, and most of the backscatter is returned from relatively close in, so that truncation of the fog illumination by the sign can be neglected. Equating the contrast ratio to visibility threshold ϵ_v as before, and solving for range, produces:

$$R = \frac{1}{S} \log_e \frac{B_o^*}{B_b \epsilon_v}$$

where B_b is now the headlight backscatter; or

$$R = \frac{V}{2.81} \log_e \frac{B_o^*}{B_b \epsilon_v}$$

where V is the equivalent standard daylight visibility fog density range ($\epsilon_d = 0.06$).

Table C-4 gives the calculated visibility for this case.

TABLE C-4. NIGHTTIME SIGN VISIBILITY

Fog Density		Headlight Brightness (Foot Lam.)	Sign Visibility Distance - Ft. (meters)	
Visibility Feet (meters)	Extinction Coefficient		Neon	Bulb Matrix
36 (11.0)	.0762	5.28	56 (17.1)	78 (23.8)
72 (22.0)	.0391	4.56	116 (35.4)	161 (49.1)
144 (43.9)	.0196	3.77	240 (73.2)	330 (100.7)
360 (109.8)	.00782	2.14	675 (205.9)	900 (274.5)

C2-6 DISCUSSION OF THE RESULTS

The results clearly show that the matrix sign can be seen further away under reduced visibility conditions. Whether the visibility of either sign is adequate is something that will have to be evaluated by the individual user.

The fog typical of a given area, for example, may not produce the very large horizon brightness levels which cause the most loss in daylight visibility. Also, it is generally conceded that warning signs are most effective when located just outside the low visibility area.

The models used in the analyses are relatively crude; however, they are believed to be representative. For example, the contrast ratio threshold level ϵ is a function of the background brightness, the size of the object being viewed, and the viewing time. The values used are representative of moderate to low daytime brightness, an object size subtending an angle of about 0.5 degree, and viewing time on the order of 0.5 second. Increasing the background brightness, object size, and viewing time produces a moderate improvement (lowering) of the threshold level. Reducing any variable by appreciable amounts will produce a large degradation in contrast discrimination capability.

The neon tubing diameter of 15 mm subtends an angle of 0.5 degree at a distance of less than 10 feet (3.1 m), and beyond 50 feet (15.3 m) is definitely into the resolution area where degradation occurs. The long dimension of the individual letter, however, is well above the critical region, so that the degradation is probably not extensive. The contribution of the multiple tubing used in the letters has not been included. It should offset somewhat the degradation caused by the small tubing size.

The effect of light scattered from the sign in the direction of the observer has not been included; i.e., the "halo" seen around lights in fog. In the case of the neon signs, its effect should improve the visibility by adding to the apparent width of the tubing, provided that the letters are sufficiently large so that the adjacent segments of the numeral are still distinguishable. Virtually all studies on the color of light in fog have indicated that color is not an important consideration in fog visibility.

The color of the neon might, however, have a very slight advantage by providing a color contrast as well as an intensity contrast. Any difference, however, will at best be small at the low contrast ratios existing at first detection.

The diameter of the R-20 reflector bulbs used in the matrix signs is between 2.25 and 2.50 inches (5.7 to 6.4 cm), considerably larger than the diameter of the neon tubing. Degradation in contrast ratio threshold levels due to small image size should, therefore, be less of a consideration than with the neon tubing. As was mentioned earlier, the bulbs in the matrix signs are being operated well below the design operating point of the bulbs. Increasing the brightness will increase the distance at which the sign is visible, particularly for the daylight fogs. Care, however, should be taken that excessive glare is not produced, by limiting the brightness in the clear, and at night.

Appendix C-3

SPECIAL FEATURES EVALUATION: NEW JERSEY TURNPIKE STUDY OF SPEED LIMIT/SPEED WARNING SIGN RELATION TO DRIVER BEHAVIOR

C3-1 INTRODUCTION

The New Jersey Turnpike offered a unique opportunity to examine the relation between speed signing and driver behavior. This is due to the fact that about thirty five miles (56.0 Km) of the roadway are instrumented with vehicle detectors, at a spacing of one half mile (0.80 Km). The system can operate in a completely automatic mode. Its variable message speed limit (SL) and speed warning (SW) signs are controlled remotely by computer. The computer has the capability of recording all system data on tape for a period of about 24 hours. The recorded data includes one minute summaries of vehicle counts and occupancies over each detector, as well as information on sign displays and status, and equipment malfunctions.

C3-2 OBJECTIVES

This special features evaluation had the following objectives:

- Examine the effectiveness of SLSW signing in lowering vehicle speeds during reduced visibility
- Examine the usefulness of vehicle detector data as a possible input to the control logic for determining variable message sign displays

The evaluation was to be conducted almost exclusively through the use of New Jersey Turnpike System tapes which were mounted on request, with the cooperation of NJTP personnel.

C3-3 SLSW SIGNING EFFECTIVENESS

The objective of this part of the evaluation was to determine the extent of SLSW signing effectiveness in modifying driver behavior in fog.

Most of these steps can be carried out by analyzing the one minute NJTP system data summary tapes.

C3-4 UTILITY OF VEHICLE SENSOR DATA FOR CONTROL OF VARIABLE MESSAGE SIGN DISPLAYS

The objective of this part of the special evaluation was to determine whether motorist reaction to reduced visibility is measurable, early enough, and sufficiently regular to allow it to be used as a source of information for changing variable message sign displays.

The procedure is to observe vehicle speeds over selected detectors as reduced visibility sets in. The effect being sought is a significant decrease in observed speed in advance of any speed warning message displays, which can be correlated with reduced visibility.

The procedures described here can be used simultaneously to obtain information on the "advance warning" possibilities inherent in the vehicle speed data. The only requirement is that the detectors chosen for examination must be within the fog area, out of sight of any speed warning or speed limit and must be observed during a period when it is known that reduced visibility conditions are setting in.

C3-5 DATA ANALYSIS

Three incidents originally thought to have involved fog were captured on NJTP data tapes -- 8/31/77, 9/17/77 and 9/30/77. In addition five tapes were made containing data taken during normal weekday conditions. These tapes were to have established a baseline for normal behavior. Modified behavior would be determined by comparing vehicle speeds in fog over detectors upstream and downstream of selected SLSW signs with vehicle speeds during normal visibility.

The existence of differences in driving behavior was to have been inferred from statistical comparisons of the upstream and downstream mean speeds, speed variances and skewness during normal and fog conditions. The existence of fog conditions can be determined by checking the operator's system log and correlating this with operator-trooper voice communication recordings.

The evaluation of sign effectiveness consists of the following steps:

- Determine fog limits from highway patrol and NJTP personnel
- Locate first group of signs which display reduced speed limits due to fog, and determine time
- Select vehicle detectors outside the fog area and out of sight of the first sign of the group; in fog area and in advance of sign; and beyond the sign
- Establish normal speed conditions over detectors
- Eliminate congestion, accidents, rain or other possible causes of speed change
- Examine speed profiles over detectors before and during fog
- Compare with normal conditions

Figure C-8 is a printout of a typical page of data from NJTP one minute summaries of system data. It shows that one minute accumulations of volume (MVOL) and occupancy (OCC) over two vehicle detectors, one upstream and one downstream

SUN JULY 18,1977 — NORTH BOUND INNER ROADWAY

	UPSTREAM DETECTOR (725)				SL SIGN(83R)		SW SIGN(83L)		DOWNSTREAM DETECTOR (729)			
TIME	MVOL (VEH)	OCC (1/60 SEC)	SPD (MPH)	SPOCC (MPH)	ACT (MPH)	STAT	ACT	STAT	MVOL (VEH)	OCC (1/60 SEC)	SPD (MPH)	SPOCC (MPH)
845	17	237	61.62	61.62	60N	M		M	17	248	58.89	58.89
846	17	233	62.68	61.99	60N	M		M	16	230	59.76	59.20
847	13	169	66.08	63.42	60N	M		M	15	213	60.50	59.65
848	11	146	64.73	63.88	60N	M		M	10	145	59.25	59.51
849	11	141	67.02	64.94	60N	M		M	11	163	57.98	58.97
850	18	252	61.36	63.71	60N	M		M	13	179	62.39	60.17
851	11	152	62.17	63.17	60N	M		M	20	298	57.66	59.29
852	13	189	59.09	61.74	60N	M		M	11	167	56.59	58.34
853	10	139	61.81	61.77	60N	M		M	13	198	56.40	57.67
854	17	241	60.60	61.36	60N	M		M	7	107	56.20	57.15
855	11	150	63.00	61.93	60N	M		M	18	269	57.49	57.27
856	20	277	62.03	61.97	60N	M		M	12	187	55.13	56.52
857	20	273	62.94	62.31	60N	M		M	16	243	56.57	56.54
858	19	260	62.78	62.47	60N	M		M	16	237	58.00	57.05
859	10	150	57.27	60.65	60N	M		M	18	280	55.23	56.41

UPSTREAM SPD STATISTICS
SPD MEAN = 62.35 MPH
SPD VAR = 5.99 MPH*MPH
NO VALID SAMPLES = 15

DOWNSTREAM SPD STATISTICS
SPD MEAN = 57.87 MPH
SPD VAR = 4.06 MPH*MPH
NO VALID SAMPLES = 15

Figure C-8. New Jersey Turnpike One-Minute System Data Dump

of a speed limit (SL) and speed warning (SW) sign pair. Average speed during the one-minute period (SPD) and sign message and sign repair status data are also shown (ACT and STAT).

The baseline data were analyzed to determine the level of significance which could be attached to small differences in observed speed -- either over the same detector at different times or over two consecutive detectors. This turned out to be high, indicating that normal driving behavior over a given detector is a statistically regular parameter, and thus a comparison might be expected to give reasonable results.

Unfortunately, two of the fog incidents which were captured on tape were accompanied by such heavy rain that it would have been impossible to separate speed reductions due to fog from speed reductions due to rain. The third incident which was recorded on tape involved only fog, but no speed reductions were posted on the SLSW signs. Thus, sign effectiveness could not be determined.

An effort was made to determine the onset of the fog condition in the third tape by listening to NJTP voice recordings of conversations between State troopers and the system operator. This would have permitted an analysis of vehicle detector data from the same time frame to determine whether there was any observable decrease in vehicle speeds. This decrease could then have been attributed to reduced visibility after ruling out congestion and incidents.

However, it proved to be impossible to identify a time before which there was good visibility and after which there was poor visibility. In part, this was due to the fact that each of the 20 tracks of tape data had to be searched through its entire four or five hour length, in real time, to identify a significant occurrence.

No fog incidents which were not also accompanied by rain have been recorded since the 9/30/77 date. Thus, the experiment did not succeed in producing the expected results. However, it is felt that the procedure was sound and that the experimental results would constitute useful knowledge for the design of reduced visibility systems.

Appendix D

EVALUATION RATIONALE FOR ASSIGNING UTILITY MODEL COMPLIANCES IN ECONOMIC EVALUATION

D-1 INTRODUCTION

The major system objectives and the associated utility measures of the RVG utility model are described in the following paragraphs. The utility measures listed under each objective are descriptive of the extent to which a given system attains that objective. Their function, therefore, is to make a comparison between systems possible. The following descriptions are intended to provide a common basis of understanding, and to provide a rationale for assigning compliance values in the economic evaluation of the sample systems. Tables D-1 through D-5 provide a record of how this rationale was used in assigning compliance values to the sample systems which were evaluated.

D-2 OBJECTIVE I - ROADWAY OPERATION

The most important objective of a reduced visibility system is to preserve the operation of the roadway at a level as close as possible to that of normal visibility conditions. The achievement of this goal is evidenced primarily by:

- Reduction in number of accidents (attributable to RV)
- Preservation of a high service level

These two parameters were, therefore, selected as the utility measures.

a. Utility Measure 1 - Reduce Accidents

The choice of this measure needs little justification in itself, but some discussion is desirable of how a system may be judged in respect to its ability to reduce accidents.

In the case of a system which has been implemented, the obvious way is to obtain objective evidence in the form of before and after accident records. Even where those exist, however, the evidence may not be conclusive, since many uncontrollable factors influence accident rates.

In this case, as well as in the case of comparing candidate system configurations which have not yet been built, it is necessary to use indirect evidence. It may reasonably be inferred that certain system characteristics or treatments are more effective than others in reducing accidents, even when hard data is lacking.

For example, reflective pavement markers must be given a lower compliance in accident reduction than active lights set into the pavement because the

TABLE D-1. UTILITY BACK UP DATA - ARIZONA

Objectives and Utility Measures	A_1	A_2	A_3	A_4
I. ROADWAY OPERATIONS				
1. Reduce Accidents	Little effect by itself	No statistical evidence; variability in RV incidence hard to account for	About the same as A_2	About same as A_3
2. Maintain High Service Level	Little effect by itself	Motorists seemed confused and in need of guidelines for RV behavior.	Instructions to drivers help reduce confusion	About same as A_3
II. SATISFY PUBLIC DEMAND				
1. Provide Credible Advanced Warning	Good if weather forecast provides good information and motorist is in high signal strength area and listening	Low credibility because signs often on when no dust storm in area	Better credibility than A_2 because of broadcast radio	Perhaps slightly less than A_2 because of smaller number of signs
2. Reduce Driver Stress	Some help in providing instructions on what to do	Low	Radio instructions help if driver has radio on; motorist reaction positive	Same as A_3
3. Public Reaction	Low; taken for granted	Performance of system got mixed response	Favorable	Perhaps slightly less than A_3; fewer signs
III. RELIABILITY AND MAINTAINABILITY				
1. Reliability	High; provided all stations broadcasting	Overall availability fairly high but message sign false alarm problem	Slightly better than A_2; signs have only two positions instead of three	Higher than A_3; smaller numbers of signs to repair and maintain
2. Preventive Maintenance Requirements	Part of regular broadcasting routine	May require more to reduce false alarm	Slightly better than A_2; signs have only two positions instead of three	Higher than A_3; smaller numbers of signs to repair and maintain
3. Field Maintenance	Fixed signs need occasioned attention	Frequently unable to operate signs; tone system uses outdated components	Slightly better than A_2; signs have only two positions instead of three	Higher than A3; smaller numbers of signs to repair and maintain
4. Central Maintenance	Very little, part of regular routine	Maybe problem with transmitter output quality	Slightly better than A_2; signs have only two positions instead of three	Same as A_3
IV. SYSTEM OPERATION				
1. Manual Operation		Manually operated	Slightly better than A_2; signs have only two positions instead of three.	Same as A_3
2. Operating Complexity	Simple	Every sign individually monitored and controlled; often confusing	All signs activated simultaneously; simpler and easier; two messages only	Same as A_3
3. Central Control Capability	Some flexibility in message and format	Limited to ability to change sign message	Limited	Same as A_3
4. Backup Capability	None	Signs can be manually operated on site	Same as A_2	Same as A_3
V. MONITORING CAPABILITY				
1. Traffic Operations	None	None	Same as A_2	Same as A_3
2. System Functions	None	Sign messages are monitored and displayed in central	Same as A_2	Same as A_3
VI. FLEXIBILITY				
1. Ease of Modification	Difficult	Difficult	Same as A_2	Same as A_3
2. Ease of Expansion	Possible by adding other stations to network	Possible, but not simple especially in other remote areas	Same as A_2	Same as A_3
VII. SECONDARY USES				
1. Data Processing	None	None	Same as A_2	Same as A_3
2. Non-RV Message Information	Flexible message and format	Limited quantity; fixed message	Broadcast radio adds flexibility	Same as A_3
VIII. INSTALLATION DISRUPTION				
1. Service Disruption	None	Minor	Same as A_2	Fewer signs than A_2
2. Installation Complexity	None	Moderate	Same as A_2	Fewer signs than A_2
3. Schedule Feasibility	Good	Good	Same as A_2	Fewer signs than A_2

TABLE D-2. UTILITY BACK UP DATA

Objectives and Utility Measures	California		New Jersey Turnpike	
	C_2	C_3	N_1	N_2
I. ROADWAY OPERATIONS				
1. Reduce Accidents	Lacking evidence. Potential limited by number of trucks available	Similar to C_2; maybe slightly more effective	Lacking evidence	Fog detection adds small potential
2. Maintain High Service Level	Effective when present	Similar to C_2; maybe slightly more effective	Depends on motorist following recommendations	Fog detection adds small potential
II. SATISFY PUBLIC DEMAND				
1. Provide Credible Advance Warning	Credibility enhanced by on-site judgment of traffic personnel	Similar to C_2; maybe slightly more effective	Good combination of weather service and trooper judgment	Advanced warning capability slightly enhanced
2. Reduce Driver Stress	Lacks evidence	Similar to C_2; maybe slightly more effective	Questionable	Same as N_1
3. Public Reaction	Trucks are familiar objects, not likely to be considered as specific for RV	More dynamic and perceptible to public	Taken for granted for the most part	Same as N_1
III. RELIABILITY AND MAINTAINABILITY				
1. Reliability	High; mechanically operated components only	Reliability decreased relative to C_2 by electronic and hydraulic systems	High availability, even though system is very sophisticated	Added equipment and communications will slightly reduce availability
2. Preventive Maintenance Requirements	Very little required	Reliability decreased relative to C_2 by electronic and hydraulic systems	Fairly high	Added equipment and communications will slightly reduce availability
3. Field Maintenance	Little required	Reliability decreased relative to C_2 by electronic and hydraulic systems	Enhanced by failure reporting and monitoring	Added equipment and communications will slightly reduce availability
4. Central Maintenance	-	-	Enhanced by failure reporting and monitoring	Added equipment and communications will slightly reduce availability
IV. SYSTEM OPERATION				
1. Manual Operation	Normal system	Normal system	Operator retains control over system functions if desired	Added equipment and communications will slightly reduce availability
2. Operating Complexity	Very simple	Little sophistication required to operate	Some sophistication required to operate	Same as N_1
3. Central Control Capability	-	Same as C_2	High	Slightly enhanced ability to isolate log location
4. Back Up Capability	Spare truck available	Same as C_2	Signs can be manually operated	Same as N_1
V. MONITORING CAPABILITY				
1. Traffic Operations	Traffic personnel on site	Same as C_2	Vehicle detectors provide good surveillance	Same as N_1
2. System Functions	-	Sign display repeated on display within truck cab	System function and equipment function continuously monitored	Same as N_1
VI. FLEXIBILITY				
1. Ease of Modification	Low	Low	Low	Same as N_1
2. Ease of Expansion	Easily expanded system	Same as C_2	Low	Same as N_1
VII. SECONDARY USES				
1. Data Processing	None	Same as C_2	Two computers capable of same data processing in slack periods	Same as N_1
2. Non-RV Message Information	Messages limited only by word length	Repertoire limited to cassette messages	Main function of system is non-RV	Same as N_1
VIII. INSTALLATION DISRUPTION				
1. Service Disruption	None	None	Considerable	Same as N_1
2. Installation Complexity	Negligible	Negligible	Considerable	Same as N_1
3. Schedule Feasibility	Very good	Good	High risk compared to simpler system	Same as N_1

TABLE D-3. UTILITY BACK UP DATA - OREGON

Objectives and Utility Measures	O_2	O_3	O_4
I. ROADWAY OPERATIONS			
1. Reduce Accidents	No statistical evidence	Some evidence of accident reduction	Addition of fog detectors raises potential for slightly reduced accidents
2. Maintain High Service Level	No statistical evidence	Not as much potential as with active guidance	Same as O_3
II. SATISFY PUBLIC DEMAND			
1. Provide Credible Advance Warning	Limited credibility because of time to display and fold down signs	Good because of fast patrol response, 24 hour operation of police headquarters, short roadway segment	Advanced warning and credibility slightly improved by fog detection
2. Reduce Driver Stress	Little evidence	Little evidence	Same as O_3
3. Public Reaction	Taken for granted	Good	Same as O_3
III. RELIABILITY AND MAINTAINABILITY			
1. Reliability	High	Availability of system fairly high; but leased line service is bad	Additional equipment will reduce reliability somewhat
2. Preventive Maintenance Requirements	Little required	Some preventive maintenance includes necessary to verify sign operation	Additional equipment will reduce reliability somewhat
3. Field Maintenance	Little required	Tone communication gear failure frequent; sign maintenance good	Additional equipment will reduce reliability somewhat
4. Central Maintenance	-	Central equipment simple and easy to maintain	Additional equipment will reduce reliability somewhat
IV. SYSTEM OPERATION			
1. Manual Operation	-	Manual	Same as O_3
2. Operating Complexity	-	Operation is simple	Same as O_3
3. Central Control	-	Several types of signing available	Perhaps slightly improved over O_3 by ability to isolate fog location quickly
4. Back Up Capability	-	Signs can be operated on-site	Same as O_3
V. MONITORING CAPABILITY			
1. Traffic Operations	-	None	Same as O_3
2. System Functions	-	Application of power to signs monitored, but not message display	Same as O_3
VI. FLEXIBILITY			
1. Ease of Modification	Very little	Not easily modified	Same as O_3
2. Ease of Expansion	Easy	Not easily modified	Same as O_3
VII. SECONDARY USES			
1. Data Processing	None	None	Same as O_3
2. Non-RV Message Information	None	Has message capability for other traffic conditions	Same as O_3
VIII. INSTALLATION DISRUPTION			
1. Service Disruption	Little	Overhead signs cause some disruption	Same as O_3
2. Installation Complexity	Simple	Medium level sophistication	Same as O_3
3. Schedule Feasibility	Very good	Good	Same as O_3

TABLE D-4. UTILITY BACK UP DATA - VIRGINIA

Objectivee and Utility Measuree	V_1*	V_2	V_3	V_4	V_5
I. ROADWAY OPERATIONS					
1. Reduce Accidente	No etatietical evidence, daylight operation only	Some evidence and better potential tban V_1, operatee night or day	Slightly more potential than V_2 becauee of added eigne	Less unprotected time snd eiightly more potential than V_2	Slightly better than V_4; larger eigne at start of hazard area
2. Maintain High Service Level	No etatieticei evidence, daylight operation only	Some evidence and better potential than V_1, operatee night or day	Slightly more potential tban V_2 becauee of added eigne	Vehicle detectore make eome incident detection possihle	Sligbtly better than V_4; larger signs at etart of hazard area
II. SATISFY PUBLIC DEMAND					
1. Provide Credible Advance Warning	None	Not automatic. Central not easily acceesible. Turn-on and Turn-off sometimes delayed	Same as V_2	Automatic operation; inetrument polling; speed eign-ing correlated to obeerved epeede	Slightly better than V_4; larger eigns at etart of hazard area
2. Reduce Driver Streee	Only at night and in light to medium fog	Effective night or day	Same as V_2	Same as V_2	VMS signe within hazard area may not help; hard to eee and read in dense fog
3. Public Resction	Low	Favorable	Same as V_2	More favorable because of better credihility	More potential for favorable resction than V_4
III. RELIABILITY AND MAINTAINABILITY					
1. Reliability	High	Lighte generally avoidable but other eubeyeteme troubleeome	Same ae V_2	Improved through better communicatione gear end failure monitoring	Slightly more complex than V_4 because of added mes-eage eigne
2. Preventive Maintenance Requiremente	Very little	Periodic tour of facility necessary to detect burned out lighte and clean light fixture houeinge	Same ee V_2	Light circuit moni-toring to improve feilure detection	Requiree slightly more than V_4
3. Field Maintenance	Period replace-ment	Require frequent bulb replacement. Traffic impeded during bulb cbange process	Same as V_2	Lees frequent re-placement necce-eary since time-on for teet is less	Requiree slightly more tban V_4
4. Central Main-tenance	-	High for commu-nicatione; low for high voltage equipment	Same se V_2	Eseier maintenance at relocsted central site; solid etate technology; com-puter self-test	Same as V_4
IV. SYSTEM OPERATION					
1. Manual Operation	-	Manually operated; no alternative mode	Same es V_2	Manual overide capability for sye-tem functione	Same ae V_4
2. Operating Com-plexity	-	Simple	Same as V_2	Simplified control panel and eystem dieplay mep	Same as V_4
3. Central Control Capability	-	Limited	Same es V_2	High	Same as V_4
4. Backup Capability	-	None	Same as V_2	Alternetive menual mode in event of computer failure	Same ae V_4
V. MONITORING CAPABILITY					
1. Traffic Operations	-	None	Same as V_2	Vehicle detectore permit some traf-fic monitoring	Same as V_4
2. Syetem Functions	-	Some provided but up to eign relay level only	Same as V_2	Meeeage eigns; communicatione; videogrsphs and computer ere mon-itored	Same as V_4
VI. FLEXIBILITY					
1. Eeee of Modifica-tion	Difficult	Better than V_1 but not easy	Same as V_2	Signe may be op-erated independ-ently of detectore if desired; non-RV meeeagee could be provided	Same as V_4
2. Ease of Expan-eion	Easy	Difficult; conduit and communica-tione sre probleme	Same as V_2	Same as V_2	Same as V_4
VII. SECONDARY USES					
1. Data Proceeeing	-	None	Same as V_2	Spare computer capability svailable for data processing	Same as V_4
2. Non-RV Meeeage Information	-	None	Same as V_2	Poeeible, if signe provided	Same as V_4
VIII. INSTALLATION DISRUPTION					
1. Service Dieruption	Little	Have closures longer than for V_1	Seme as V_2	Seme as V_2	Same as V_4
2. Installation Com-plexity	Easy	Fairly complex	Same as V_2	Same as V_2	Same se V_4
3. Scbedule Feasibility	Good	Not unreaeonable	Same as V_2	Same as V_2	Same as V_4

*Also bolds for Oregon delineation eyetem (O_1) and California delineation system (C_1)

TABLE D-5. UTILITY BACK UP DATA - WYOMING

Objectives and Utility Measures	W_1	W_2	W_3	W_4
I. ROADWAY OPERATIONS				
1. Reduce Accidents	No statistical evidence	Evidence is not firm, but potential is greater than W	Evidence not firm, but diversion removes vehicles from roadway and reduces exposure	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
2. Maintain High Service Level	No statistical evidence	Snow drifting reduced	Depends on driver compliance	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
II. SATISFY PUBLIC DEMAND				
1. Provide Credible Advance Warning	Good if weather warning is timely, motorist is turned in, and is in high signal area	None	Weather station and patrol provide reliable warning	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
2. Reduce Driver Stress	Probably small effort	Visual evidence is reassuring in areas free of blowing snow, but is limited to fenced roadway sections	Uncertain drivers given option of alternate roadway	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
3. Public Reaction	Little impression according to surveys	Good	Public reactions generally good	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
III. RELIABILITY AND MAINTAINABILITY				
1. Reliability	Overall availability fair	High	Overall availability good	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
2. Preventive Maintenance Requirements	Fair	Little required	Good	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
3. Field Maintenance	Conduit and cable have rodent problem; communication eqpt. outdated	Little required	Some minor problems	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
4. Central Maintenance	Minimal	-	Computer maintained under contract; central effort is not unreasonable	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
IV. SYSTEM OPERATION				
1. Manual Operation	Manual only	-	Manually selected, implemented by computer	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
2. Operating Complexity	Simple	Passive	Simple	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
3. Central Control Capability	Minimal	-	Very flexible on selection of signs from central	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
4. Backup Capability	None	-	None	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence

Table D-5. Utility Back Up Data - Wyoming (Continued)

Objectives and Utility Measures	W_1	W_2	W_3	W_4
V. MONITORING CAPABILITY				
1. Traffic Operations	None	-	None	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
2. System Functions	None	-	Sign message arrival, but not display, is verified	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
VI. FLEXIBILITY				
1. Ease of Modification	Two conductor cable limits capability	-	Difficult to modify functions	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
2. Ease of Expansion	Conduit and central difficult to expand	Equivalent to initial installation	Up to four add'l signs could be added if desired	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
VII. SECONDARY USES				
1. Data Processing	None	-	Computer is near capacity during message transmission, otherwise could be used	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
2. Non-RV Message Information	Any broadcast material can be supplied	-	General advisory messages available and arbitrary ones possible	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
VIII. INSTALLATION DISRUPTION				
1. Service Disruption	Minor	Low	Minor - two signs erected	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
2. Installation Complexity	Simple	Low	Requires higher level of personnel than W_2 for electronics	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence
3. Schedule Feasibility	Good	Good	Good	Presence of all components W_1, W_2, W_3 provides better potential for improvement, but no firm evidence

latter are visible during the day, while reflective markers are much less effective during daylight hours than at night. If delineation and demarcation have any effect at all on accident rates, then, the most easily seen demarcation should have the greatest effect and should get a higher rating.

b. Utility Measure 2 - Maintain High Service Level

Service level is a well-defined measurable quantity for a given roadway. However, in the case of reduced visibility systems, it is not often feasible to try to measure the effect on service level of a specific system feature.

Reduction of delays, alleviation of congestion, and smooth, uniform speed flow are indications of a high level of service. System features which have an effect on service level are signing, lighting, guidance, convoying and other advisory and control measures. Definitive data are lacking, but studies seem to show that dynamic methods are generally more effective than static ones.

D-3 OBJECTIVE II - SATISFY PUBLIC DEMAND

The reduced visibility system is built primarily for the user's sake. Therefore, it is important that the system designer take into account how the problem is perceived by the user. If this is not done, the wrong problem may have been solved.

Public satisfaction with reduced visibility measures follows from having clear, unequivocal and timely information about the existence of bad driving conditions. Equally important, the public desires a system which will reduce the stress of driving in RV conditions to as low a level as is economically feasible. The extent to which a given system possesses these features may sometimes be judged from the reaction of the public, whether expressed in letters, chance comments on CB radio channels, newspapers or radio items.

Thus, the utility measures chosen for determining whether public demand has been satisfied are:

- Provision for credible advanced warning
- Reduction of driver stress
- Public reaction

a. Utility Measure 1 - Provide Credible Advanced Warning

Credibility is an important issue because the driver is being asked to comply voluntarily with instructions or advice. Usually, no enforcement is attempted. System credibility depends on early and reliable warning of reduced visibility conditions, coupled with unambiguous signing messages and an early return to normal conditions when the problem has dissipated.

Factors which influence system credibility are:

- The variability of the RV condition in time and space
- The number and type of RV detectors
- The extent of "instrument-polling" which can be used to cross-check instrument readings

b. Utility Measure 2 - Reduction of Driver Stress

Driver stress is measurable parameter, but to measure the difference in stress between a reduced visibility environment and a normal one is a very difficult and expensive task. Tail light applications, palm moisture, eyeball movement, heart rate and breathing rate can be indicative of changes in driver stress, but are not usually monitored.

Reduction in driver stress is inferred, therefore, from the presence of system elements which past experience and public reaction have identified as promoting easier driving in reduced visibility. The presence of pavement lights or reflectors which delineate roadway edges and lanes is a more important element than advisory signing in providing the continuous orientation cues which are necessary. The presence of advisory signing is important in relieving stress concerning decisions in the face of unknown contingencies. Speed warning signs probably do not provide much relief unless drivers have good reason to believe everyone is obeying them.

c. Utility Measure 3 - Public Reaction

The objective, it will be recalled, is to satisfy public demand and the manner in which the attainment of this objective is measured is by public reaction.

In the case of a proposed or candidate system, the question which must be answered is: to what extent will the candidate system satisfy the demands of the public for solution of a problem. This can be judged by observing reaction to similar systems elsewhere after they have been built.

In the case of an existing system which is being evaluated by means of the utility model, public reaction is more directly estimated from letters, newspaper articles, CB monitoring, surveys and the content of radio or television broadcast material relating to the system.

D-4 OBJECTIVE III - RELIABILITY AND MAINTENANCE

Reliability is expressed in terms of the mean-time-between-failures (MTBF) and maintainability is expressed in terms of mean-time-to-repair (MTTR). Reliability and maintainability together determine the "availability" of a system. Availability is, as its name implies, a measure of the probability of having a given

system available for operation when it is needed. Utility measures for this objective are:

- Reliability
- Preventive maintenance requirements
- Field maintenance
- Central maintenance

For a system composed of more or less complex components, reliability and maintainability have distinct meanings and may be determined at different levels of design. For a simple system, it is the joint concept of availability that should be kept in mind when estimating compliance for the utility measures.

Thus, for example, where there is a system with electromechanical or electronic central control equipment and field equipment, each group should be evaluated in terms of reliability and maintenance before arriving at a compliance for these measures. However, in the case of a simple "system", such as reflective markers in the roadway, it is the overall availability which is the factor to be evaluated. The availability is obviously very high for a "system" such as the markers, since only occasional attention is required to keep them in operational condition.

a. Utility Measure 1 - Reliability

Reliability is usually defined in terms of the mean-time-between-failures which can be expected of a system.

b. Utility Measure 2 - Preventive Maintenance Requirements

Preventive maintenance should be simple and should not require heavy investment of manpower. Field hardware should be provided with self-check features so that time-consuming preventive maintenance can be reduced - e.g., in the case of pavement lights for guidance, supply voltage can be monitored to detect bulb burnouts so that highway inspection trips need not be made as frequently.

c. Utility Measure 3 - Field Maintenance

Field equipment should consist of standard hardware to the greatest extent possible and should be serviceable by local maintenance personnel without specialized or complex test equipment. Communication equipment should be simple and modular. Plug-in assemblies with self-aligning and positive seating features are preferable to assemblies which require time consuming and repeated grooming, and should receive higher ratings under this utility measure.

d. Utility Measure 4 - Central Maintenance

Central facility equipment should be such as to permit rapid servicing and repair. This implies sensible physical layout, modular equipment, easy and positive

module insertion. It also implies good documentation on equipment meant to be maintained by local forces.

D-5 OBJECTIVE IV - SYSTEM OPERATION

Ease of operation, centralized control capability, use of standard symbols for control panel marking, ability to override automatic decisions when necessary and a fail-safe backup to automatic operation are the important characteristics of good system operation. A clear and unambiguous display of the control area is important especially when there are multiple system elements or a large area to cover.

a. Utility Measure 1 - Manual Override

The system should be judged by the degree to which it permits the operator to alter manually all or any part of the system which is normally automatically controlled, such as selection of operating mode, variable sign message selection and performance of or checking of system functions.

b. Utility Measure 2 - Operating Complexity

The interface between the system and the operator should be simple and straightforward. Selection of control mode, messages and other such functions should be by means of positive action devices such as push buttons. Control panels should be simple and should use standard traffic engineering terminology and symbols.

c. Utility Measure 3 - Central Control Capability

When powered equipment is involved, especially in the case of systems covering a large geographic area, central control capability is essential. System credibility, ease of maintenance and ease of operation are all enhanced by a centralized control facility.

d. Utility Measure 4 - Backup Capability

The system, if it has automatic control features, must have the capability of releasing control to local units smoothly and safely. Variable message signs must be provided with a safe backup operation mode.

D-6 OBJECTIVE V - MONITORING CAPABILITY

Monitoring capability is an objective which increases in importance with system complexity and degree of automation.

a. Utility Measure 1 - Traffic Operation Monitoring

Monitoring of traffic operation parameters such as speeds and volume makes the task of evaluating system effectiveness easier, and can provide the basis for increased system control sophistication and credibility-- e.g., modification of speed advisory message signing to bring displayed speeds more into line with observed speeds.

b. Utility Measure 2 - System Function Monitoring

Monitoring of system functions - e.g., sign message verification, communication system fault monitoring, visibility sensor self-checking-- is an extremely important feature of system design.

D-7 OBJECTIVE VI - FLEXIBILITY

Flexibility is defined here in terms of the ease with which a given system may be modified or expanded.

a. Utility Measure 1 - Ease of Modification

Systems are to be judged here on their ability to be modified in the light of changes in operating conditions, technology or environment. For example, a system may be designed in such a way as to permit any one of a number of reduced visibility sensors to be used without serious consequences in system hardware or software. Such a system should receive a superior rating in this category compared to one which is limited to the use of a single sensor type.

On a simpler level, a "system" consisting of raised pavement markers is not capable of much modification except in the spacing of delineators.

b. Utility Measure 2 - Ease of Expansion

This utility measure is concerned with the ease with which the size of the system may be increased, rather than its functional details. For example, a roadway lighting system dependent on a high voltage power source already taxed to its load limit cannot be expanded easily, even if the roadway lighting units can be added without difficulty.

D-8 OBJECTIVE VII - SECONDARY USES

This objective relates to the portion of a system which may be capable of multiple functions. Generally, this is characteristic of a computerized system.

a. Utility Measure 1 - Data Processing

One or more of the systems to be compared may possess the capability of performing functions over and above those concerned with reduced visibility. Typical secondary uses may be:

- Data collection and analysis
- Simulation
- Maintenance

b. Utility Measure 2 - Non-RV Message Information

The ability of some systems to transmit information not related to reduced visibility should be reflected in a higher utility rating. Systems with signs capable of being formatted with arbitrary messages have a wider usefulness, as do broadcast radio systems, compared to taped, fixed message HAR system.

D-9 OBJECTIVE VIII - INSTALLATION DISRUPTION

The objective here is to select a system which will involve as little disruption as possible, other things being equal.

a. Utility Measure 1 - Service Disruption

Disruption of service to the motorist should be kept to a minimum during installation. Factors which influence this are, for example:

- Type of communication; conduit and cable laying usually involve more construction and motorist delay than microwave or radio
- Vehicle sensor installation in the roadway
- Use of roadway inset lighting
- Installation of overhead sign bridges

b. Utility Measure 2 - Installation Complexity

Installation complexity varies from system to system. Selection of a transmissometer type of visibility sensor, for example, involves aligning a transmitter and a receiver with each other and keeping the alignment from deteriorating. Instrument bases, therefore, must be more carefully surveyed and built than is the case for a back scatter type of sensor. Added complexity results in a penalty for such systems.

c. Utility Measure 3 - Schedule Feasibility

This measure is primarily useful in comparing candidate systems which are in the planning stage. A system which is in existence and which was installed on schedule should nevertheless be judged on its potential for schedule slippage. Factors which influence a comparison between candidate systems are, for example, the cost and availability of funds and manpower, and weather conditions during the proposed installation period.

Appendix E

SAMPLE SYSTEM EVALUATION SUMMARIES

INTRODUCTION

This appendix presents the evaluation summaries for each of the sample RVG systems studies. The sample RVG systems that were evaluated are:

- Arizona: I-8/I-10 Dust Warning System
- California: State Route 91 Passive Delineation System
- New Jersey: New Jersey Turnpike System
- Oregon: I-5 Fog Warning System
- Virginia: I-64 Fog Warning and Guidance System
- Wyoming: I-80 System

In addition to the systems which were evaluated, several other reduced visibility systems were contacted for information during the course of the study, as part of Task D. The largest of these was the Hampton Roads, Virginia system which is part of a larger system designed for tunnel and bridge traffic control of the Chesapeake-Hampton Roads tunnel. An automatic "point" system, consisting of a videographs coupled to variable message speed signs, was computed during the study at a bridge over Genera Marsh in eastern Pennsylvania. Other systems of varying degrees of complexity are operating in both Carolina and Florida.

The system summaries consist of a docket which includes a case history of each system, tracing its evaluation and providing answers to questions such as system objectives, effectiveness, performance and economic justifiability. Also contained in the docket are the results of measure-of-need and utility cost computations.

Each evaluation docket is divided into basically five sections. These are:

- System Summary
- System Description
- System Costs and Utility

- System Measure-of-Need
- Discussion:
  - Objectives
  - Performance
  - Economic Justification

The System Summary briefly outlines, in a tabular format, the major features and elements of the system. The System Description section describes the chronological development of the system and its elements in detail.

In the System Utility and Cost section, a utility-to-cost ratio is computed for the system. The system costs were divided into implementation and annual maintenance and operation costs. For comparison purposes, all the system costs were normalized to a common date of January 1, 1977, based on an inflation rate derived from the national Consumer Price Index of the U. S. Department of Labor. In addition, the present worth, as of 1-1-77, of maintenance and operation costs projected 15 years into the future (assumed life of system) was computed based on a 6.5% inflation rate and a 10% rate, as the cost of borrowing money. The cost figure used in utility-cost computation is expressed in terms of the total present worth of the system. It was computed as follows:

Present Worth = (capital cost normalized for inflation to 1-1-77) +
(present worth of maintenance and operation costs,
projected 15 years into the future from 1-1-77)

The utility of the system was obtained by estimating system compliances in the utility model developed during the study. The model consists of a number of primary system objectives, each of which is accompanied by a group of "utility measures". The utility measures are descriptive of the extent to which the system meets the objectives under which they are listed. As a result of open discussion with the Task Force members during the course of the study program, "system values", shown in Table E-1, for each of the utility measures were agreed upon. To arrive at a system utility, a "compliance factor" ranging in value from zero to ten was estimated for each utility measure on the basis of the known characteristics of the system. The system utility was computed by summing products of system values and compliance factors.

In the fourth section, Measure-of-Need, the MON methodology developed during the study is applied to the sample system site. The MON data used for input to the MON computation process is discussed. The output results are presented in the form of MON values for the sectionalized roadway segments of the system site. Each of the computed MON values is segmented into each of its two aggregate component parts, namely, the MON_A and MON_P. The MON_A, which depends upon the accident history of the roadway segment, measures the severity of the RV hazard from accident experience data. The MON_P is computed from roadway traffic volumes, RV frequency and roadway geometry, and, therefore, measures the potential of the RV

TABLE E-1. UTILITY MODEL FOR SYSTEM EVALUATION

	Utility Measure	System Value
I.	ROADWAY OPERATION	
	1. Reduce Accidents	19.2
	2. Maintain H/S Level	12.8
II.	SATISFY PUBLIC DEMAND	
	1. Provide Credible A/W	12.6
	2. Reduce Driver Stress	3.6
	3. Public Reaction	1.8
III.	RELIABILITY & MAINTAINABILITY	
	1. Reliability	7.5
	2. Preventive Maint. Reqts	3.7
	3. Field Maint.	2.3
	4. Central Maint.	1.5
IV.	SYSTEM OPERATION	
	1. Manual Override	3.9
	2. Operating Complexity	3.9
	3. Central Control Capab.	3.3
	4. Backup Capability	1.9
V.	MONITORING CAPABILITY	
	1. Traffic Operation	4.5
	2. System Function	4.5
VI.	FLEXIBILITY	
	1. Ease of Modification	3.6
	2. Ease of Expansion	2.4
VII.	SECONDARY USES	
	1. Data Processing	2.0
	2. Non-RV Mess. Info.	2.0
VIII.	INSTALLATION DISRUPTION	
	1. Service Disruption	1.5
	2. Installation Complexity	0.8
	3. Schedule Feasibility	0.7
		100.0

hazard. The implications of the individual MON values and a system MON weighted average are discussed.

The last section of this appendix is a discussion of the system from the viewpoint of the system objectives, performance and economic justification.

Appendix E-1
ARIZONA: I-8/I-10 DUST WARNING SYSTEM

E1-1 SUMMARY

- State: Arizona
- Environmental Hazard: Blowing dust
- Site Location: Central Arizona, southeast of Phoenix
- Facility: Interstates 8 and 10, four lane limited access divided highway, AADT = 3,900 (I-8); 12,500 (I-10)
- System Length: 82 miles (131.9 Km): 18.6 miles (29.9 Km) on I-8 and 63.4 miles (102 Km) on I-10
- System Elements: Changeable message signs: rotating drum type, radio equipment (field and central), central control console with system status display map

E1-2 SYSTEM DESCRIPTION

The Arizona Dust Warning System consists of 40 changeable message signs spread throughout 82 miles (131.9 Km) of Interstates 8 and 10 in Central Arizona. Their purpose is to provide motorists with dust storm warnings. The system also incorporates the personnel and facilities of National Weather Service (NWS), the Arizona Department of Public Safety, the Arizona Department of Transportation, and 3 Phoenix-based commercial radio stations. Utilizing weather radar, the NWS is able to detect and report through its teletype network major dust storms in advance of their arrival on I-8 and I-10. Highway personnel and State Police in the field also provide advance information to the sign system control center located in the police communications central in Phoenix. Whenever a dust storm alert is posted on the system signs, the State Police contact pre-selected local radio stations requesting them to broadcast dust storm information. The selected stations have volunteered to broadcast dust storm advisories and driving instructions at ten-minute intervals during storm alert periods. The NWS and State Police continuously update information during storm activity so that appropriate sign and broadcast messages are provided to the motorist.

The system of 40 signs with changeable messages was placed into operation in 1973. These signs are spaced approximately five miles (8.04 Km) apart in both directions; with at least one sign in advance of each off-ramp in the interchange area.

With this configuration, a motorist encountering a sign in the warning mode can leave the interstate and seek shelter on the neighboring cross road. The system signs are of the rotating drum type. Each sign originally used these three display modes:

- Mode 1: Standard I-10/I-8 route shield with direction displayed
- Mode 2: "GUSTY WINDS -- USE CAUTION"
- Mode 3: "BLOWING DUST-REDUCE SPEED"

The Mode 3 sign message was augmented by two high-intensity strobe lights.

The Mode 2 and Mode 3 messages implied that the problem was local to the area of the sign, but since no local RV sensing was used, actual conditions at the sign often did not match the sign display, and credibility was lost. For this reason, the Mode 2 and Mode 3 signs were replaced by a single Mode 2 sign carrying the message "DUST STORM ALERT-RADIO 550/620/910" and the cooperation of commercial broadcast stations was enlisted. Figures E-1 and E-2 provide illustrations of the system surroundings and the Mode 2 sign display respectively.

Each sign installation was designed as a self-contained unit not susceptible to power outages. Each has its own direct current driver motor, control panel, battery pack, thermoelectric generator and LPG gas tank. Also, a radio control package (transmitter and receiver) together with coding equipment is at each location.

The control console located at the State Police communications center in Phoenix controls the mode selection for each sign. The control console consists of a map display and radio communications equipment. (See Figures E-3 and E-4.) The map display shows the geographic location of the system signs and identifies them by an alphanumeric code (e.g., A33). Activated signs are displayed on the map by illuminated dots. To activate a system sign, the operator first identifies the alphanumeric code assigned to the sign as shown on the map display. This code is then set on the sign selector tumbler mechanism and a message mode switch is positioned to the desired message mode. The operator presses the transmit button which causes a microwave radio signal to be sent to the sign requesting the message change. At the sign installation, a transmitter sends back a signal which is a verification that the message command was received. Correspondingly, the appropriate lamp on the map display is illuminated. If there is a failure in communications, the signs can be operated manually at the site. The radio system is licensed by the Federal Communications Commission for secondary tone signaling on a pair of emergency callbox frequencies.

The State is presently testing the feasibility of using solar panels as a source of electrical current to charge the battery pack which powers the sign drive motor.

Figure E-1. Typical Roadside Characteristics Along I-8

Figure E-2. Arizona Variable Message Sign: Message Mode 2

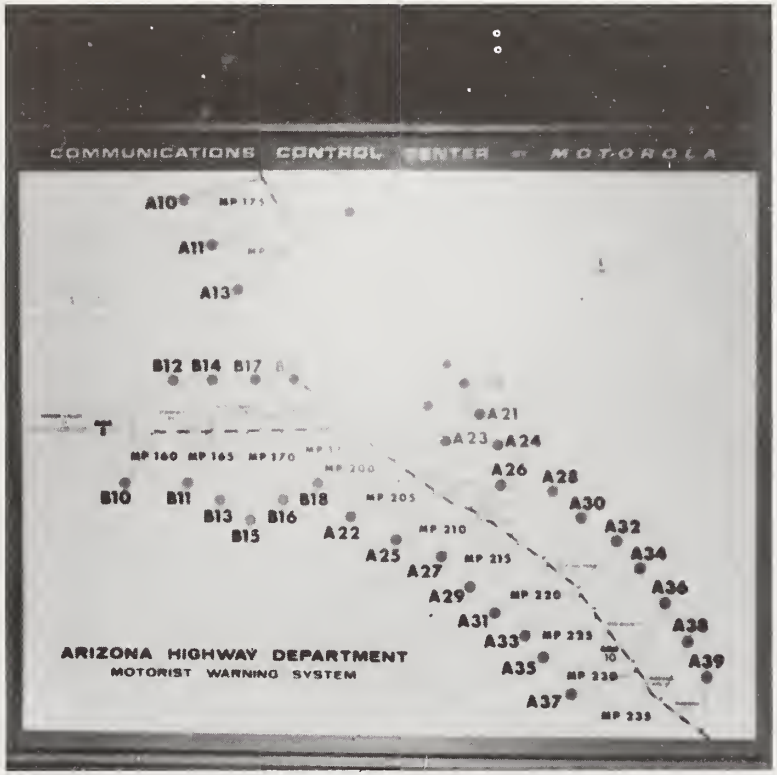


Figure E-3. Close View: Arizona System Map Display

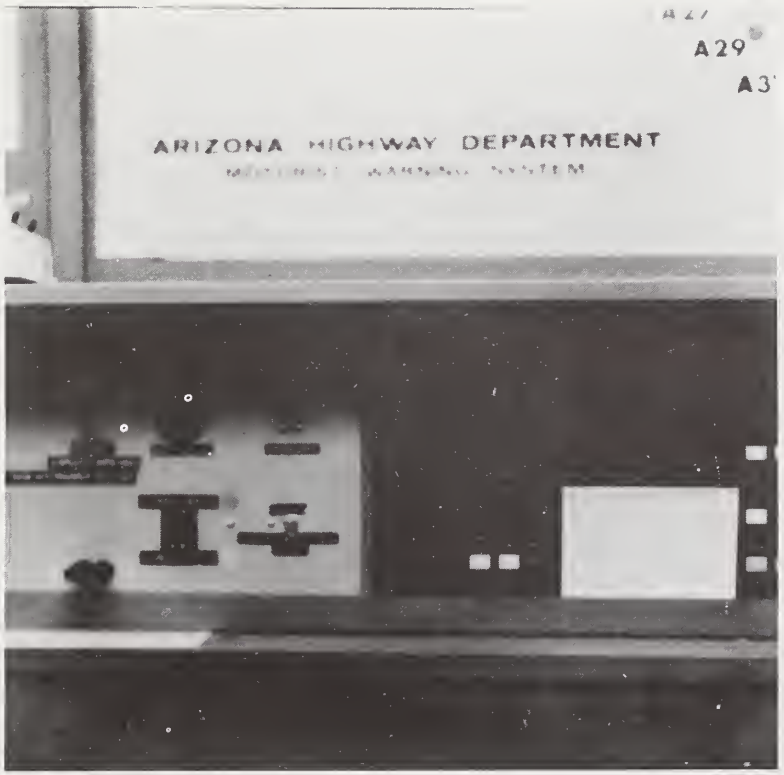


Figure E-4. Arizona System Sign Control Console at State Police Communications Center

E1-3 SYSTEM COSTS AND UTILITY

a. COSTS

Implementation, operation and maintenance costs for the Arizona system are shown in Table E-2 below.

TABLE E-2. ARIZONA SYSTEM COSTS

Item	Cost (1973)	Cost (1-1-77)
Implementation	$737,733	$1,008,000
Operation & Maintenance	$ 33,111/yr*	$ 45,230/yr
Total Present Worth of System	---	$1,537,000**

*Average annual cost after implementation

**Includes present worth of maintenance and operation cost projected 15 years into the future from 1-1-77.

b. UTILITY

Table E-3 shows the individual utility ratings for the Arizona system. The total system utility is 419.2, and the utility-to-cost ratio, using the present worth in dollars as the cost element is, therefore:

$$\frac{U}{C} \times 10^5 = \frac{419.2}{\$1,537,000} \times 10^5 = 27$$

E1-4 MEASURE-OF-NEED

To facilitate the computation of the MON, the Arizona system was divided into two segments, Interstate 10 and Interstate 8. The MON Baseline Data Maps for I-10 and I-8 are shown in Figures E-5 and E-6, respectively. The RV accident occurrence on Interstate 10 is relatively sparse with the greatest accident density occurring in MON Sections 3, 11, 14 and 20. On Interstate 8, there are a total of four accidents spread over the 28-mile (45.0 Km) section. Table E-4 shows the MON input data for I-10 and I-8. AADT volumes on I-10 correspond to a Category II system, whereas those on I-8 fall into a Category I system. The RV accident history on both interstates covers the time period from 1970 to 1975, a six-year span. MON Sections 7 and 9 on I-10 have a total of eight fatalities each, a relatively high number considering that there were only two accidents. The total RV accident frequency is the highest in MON Sections 3 and 14 on I-10. The RV estimate of 40 days per year was obtained from the National Weather Service which maintains records of dust storm activity surrounding the Phoenix metropolitan area. The geometric rankings for I-10 and I-8 are ideal since both interstates have level grades and tangent horizontal alignments.

TABLE E-3. ARIZONA SYSTEM-UTILITY RATINGS

Utility Measure	System Value	Comp.	Util.
I. ROADWAY OPERATION			
1. Reduce Accidents	19.2	2.5	48.0
2. Maintain H/S Level	12.8	2.7	34.6
II. SATISFY PUBLIC DEMAND			
1. Provide Credible A/W	12.6	6.5	81.9
2. Reduce Driver Stress	3.6	5.5	15.8
3. Public Reaction	1.8	7.5	13.5
III. RELIABILITY & MAINTAINABILITY			
1. Reliability	7.5	6.0	45.0
2. Preventive Maint. Reqts	3.7	5.0	18.5
3. Field Maint.	2.3	4.0	9.2
4. Central Maint. .	1.5	5.5	8.3
IV. SYSTEM OPERATION			
1. Manual Override	3.9	0	0
2. Operating Complexity	3.9	8.5	33.2
3. Central Control Capab.	3.3	7.0	23.1
4. Backup Capability	1.9	5.0	9.5
V. MONITORING CAPABILITY			
1. Traffic Operation	4.5	0	0
2. System Function	4.5	4.0	18.0
VI. FLEXIBILITY			
1. Ease of Modification	3.6	4.5	16.2
2. Ease of Expansion	2.4	3.0	7.2
VII. SECONDARY USES			
1. Data Processing	2.0	0	0
2. Non-RV Mess. Info.	2.0	6.0	12.0
VIII. INSTALLATION DISRUPTION			
1. Service Disruption	1.5	7.0	10.5
2. Installation Complexity	0.8	6.5	5.2
3. Schedule Feasibility	0.7	8.0	5.6
	100.0		419.2

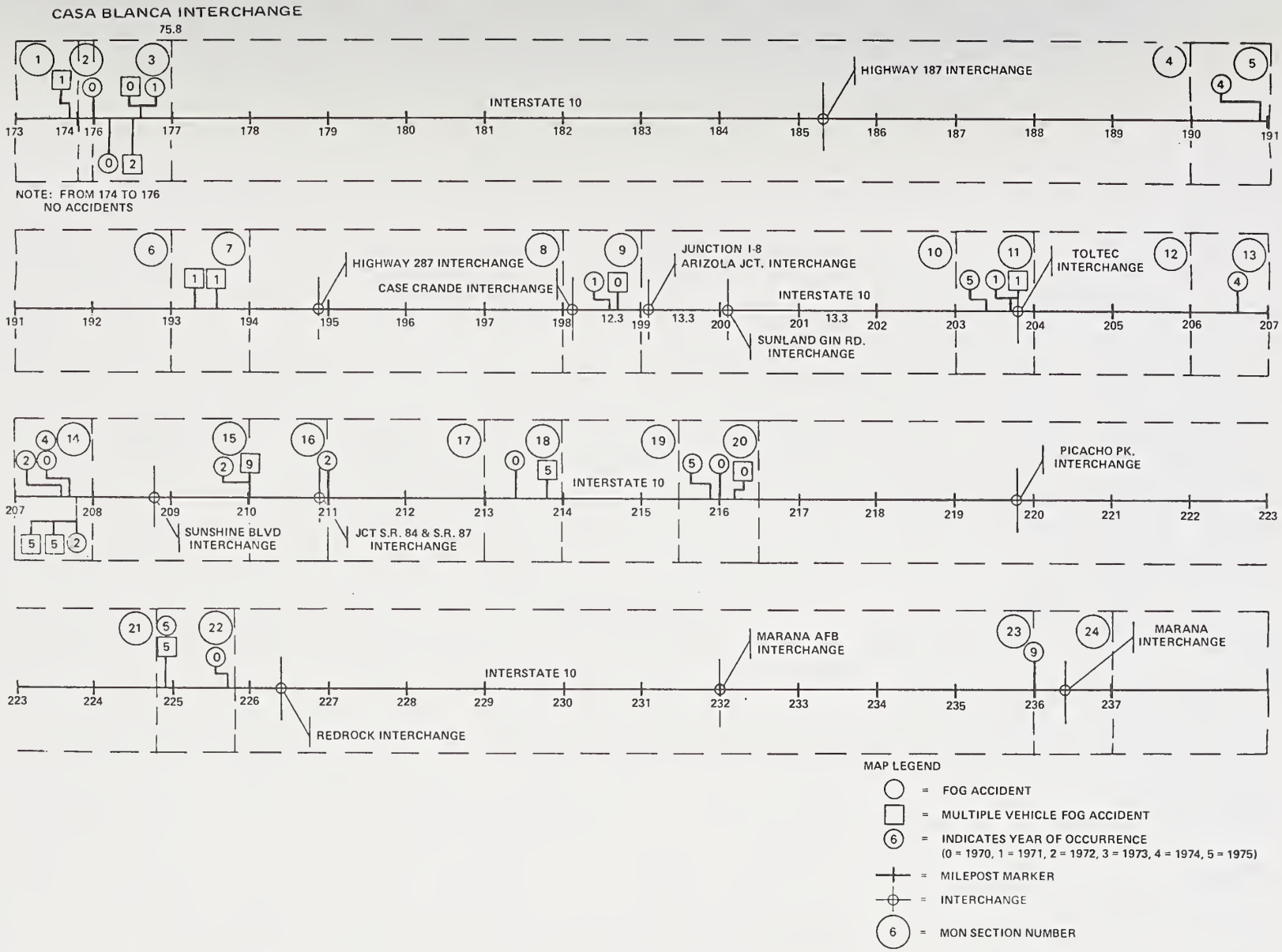


Figure E-5. Arizona (I-10) DSAS Measure-of-Need MON Baseline Data Map

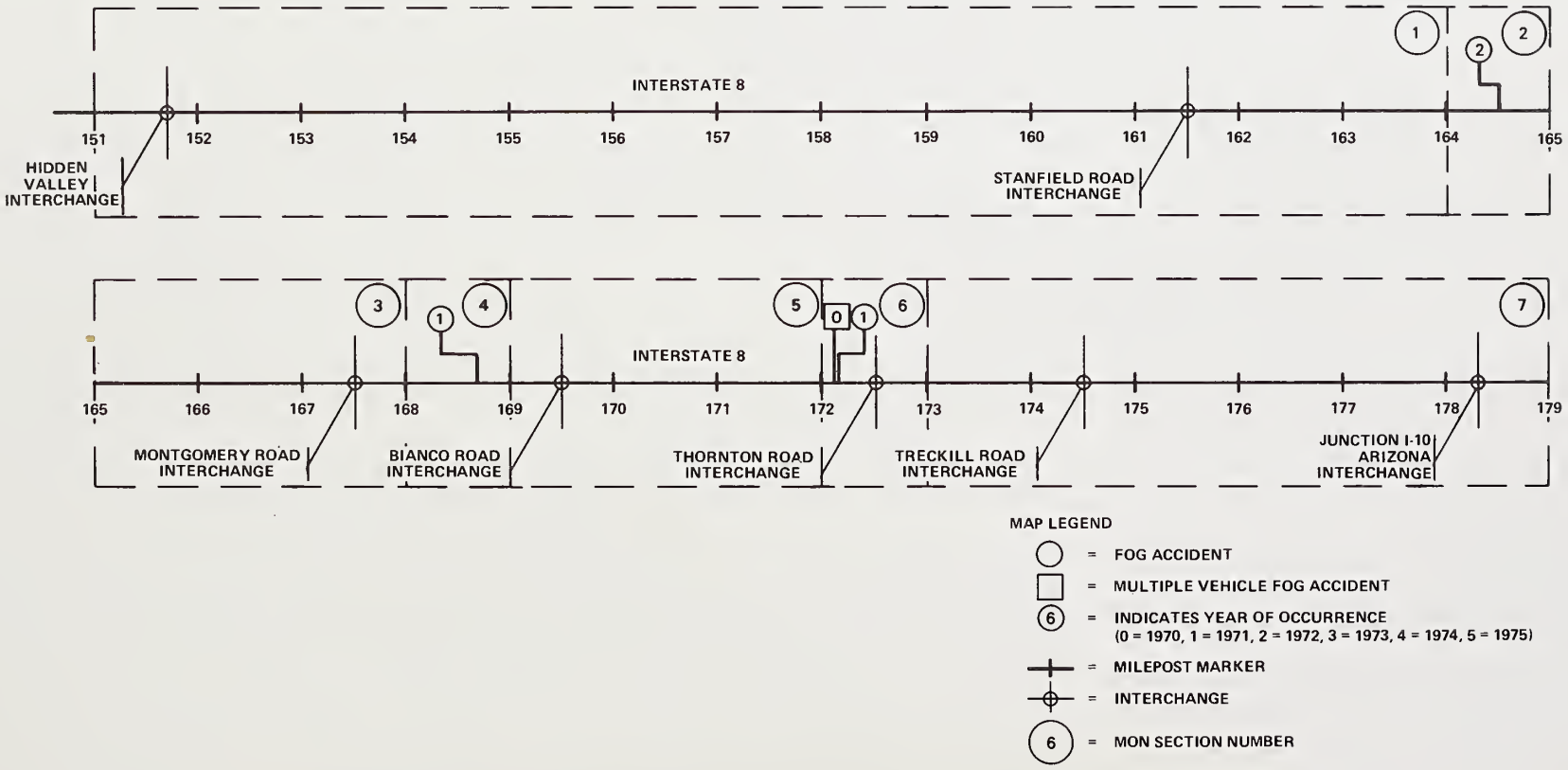


Figure E-6. Arizona (I-8) DSAS Measure-of-Need MON Baseline Data Map

TABLE E-4. ARIZONA MON INPUT DATA

ARIZONA I-1Ø (DSAS) FILE 28 REV Ø

#	LENGTH	AADT	YEARS	FATALITIES	MULTI VEH.	TOTAL	RAMPS RV	DAYS	GRADE	CURV
1	1.Ø	112ØØ	6.Ø	Ø	1	1	4	4Ø	1.ØØ	1.ØØ
2	2.Ø	112ØØ	6.Ø	Ø	Ø	Ø	Ø	4Ø	1.ØØ	1.ØØ
3	1.Ø	1Ø8ØØ	6.Ø	Ø	2	5	4	4Ø	1.ØØ	1.ØØ
4	13.Ø	95ØØ	6.Ø	Ø	Ø	Ø	4	4Ø	1.ØØ	1.ØØ
5	1.Ø	95ØØ	6.Ø	Ø	Ø	1	Ø	4Ø	1.ØØ	1.ØØ
6	2.Ø	95ØØ	6.Ø	Ø	Ø	Ø	Ø	4Ø	1.ØØ	1.ØØ
7	1.Ø	95ØØ	6.Ø	8	2	2	Ø	4Ø	1.ØØ	1.ØØ
8	4.Ø	94ØØ	6.Ø	Ø	Ø	Ø	4	4Ø	1.ØØ	1.ØØ
9	1.Ø	123ØØ	6.Ø	8	1	2	4	4Ø	1.ØØ	1.ØØ
1Ø	4.Ø	133ØØ	6.Ø	Ø	Ø	Ø	8	4Ø	1.ØØ	1.ØØ
11	1.Ø	133ØØ	6.Ø	Ø	1	4	4	4Ø	1.ØØ	1.ØØ
12	2.Ø	142ØØ	6.Ø	Ø	Ø	Ø	Ø	4Ø	1.ØØ	1.ØØ
13	1.Ø	142ØØ	6.Ø	Ø	Ø	1	Ø	4Ø	1.ØØ	1.ØØ
14	1.Ø	142ØØ	6.Ø	1	2	6	Ø	4Ø	1.ØØ	1.ØØ
15	2.Ø	14ØØØ	6.Ø	Ø	Ø	Ø	4	4Ø	1.ØØ	1.ØØ
16	1.Ø	14ØØØ	6.Ø	Ø	1	3	4	4Ø	1.ØØ	1.ØØ
17	2.Ø	14ØØØ	6.Ø	Ø	Ø	Ø	Ø	4Ø	1.ØØ	1.ØØ
18	1.Ø	14ØØØ	6.Ø	Ø	1	2	Ø	4Ø	1.ØØ	1.ØØ
19	1.5	14ØØØ	6.Ø	Ø	Ø	Ø	Ø	4Ø	1.ØØ	1.ØØ
2Ø	1.Ø	14ØØØ	6.Ø	Ø	1	3	Ø	4Ø	1.ØØ	1.ØØ
21	8.3	145ØØ	6.Ø	Ø	Ø	Ø	Ø	4Ø	1.ØØ	1.ØØ
22	1.Ø	145ØØ	6.Ø	Ø	1	3	Ø	4Ø	1.ØØ	1.ØØ
23	1Ø.2	145ØØ	6.Ø	Ø	Ø	Ø	4	4Ø	1.ØØ	1.ØØ
24	1.Ø	145ØØ	6.Ø	Ø	Ø	1	4	4Ø	1.ØØ	1.ØØ

ARIZONA I-8 (DSAS) FILE 29 REV Ø

#	LENGTH	AADT	YEARS	FATALITIES	MULTI VEH.	TOTAL	RAMPS RV	DAYS	GRADE	CURV
1	13.Ø	33ØØ	6.Ø	Ø	Ø	Ø	4	4Ø	1.ØØ	1.ØØ
2	1.Ø	39ØØ	6.Ø	Ø	Ø	1	Ø	4Ø	1.ØØ	1.ØØ
3	3.Ø	39ØØ	6.Ø	Ø	Ø	Ø	4	4Ø	1.ØØ	1.ØØ
4	1.Ø	39ØØ	6.Ø	Ø	Ø	1	Ø	4Ø	1.ØØ	1.ØØ
5	3.Ø	39ØØ	6.Ø	Ø	Ø	Ø	4	4Ø	1.ØØ	1.ØØ
6	1.Ø	39ØØ	6.Ø	Ø	1	2	4	4Ø	1.ØØ	1.ØØ
7	6.Ø	39ØØ	6.Ø	Ø	Ø	Ø	4	4Ø	1.ØØ	1.ØØ

MON values for I-10 and I-8 are shown in histogram form on Figures E-7 and E-8, respectively. On I-10, the accident potential accounts for the greatest portion of the total MON value. This is due to the relatively low RV accident frequency coupled with a high exposure to the RV environment. MON Sections 7 and 9 exceed the high threshold value and the remaining sections are above or at the medium threshold. The weighted MON average for I-10 is 28, which is above the medium threshold. Therefore, it can be inferred that the system is justifiable from the MON point of view. The MON values for I-8 are lower than those of I-10 as expected. The weighted MON average for I-8 is 16, lower than the medium threshold value. Relatively speaking, it appears that the I-8 portion of the system is less justifiable, in terms of MON, than the I-10 segment.

E1-5 DISCUSSION

a. OBJECTIVES

The Arizona system was implemented on July 1973 as an advanced warning system for dust storms in south-central Arizona. The system was installed primarily

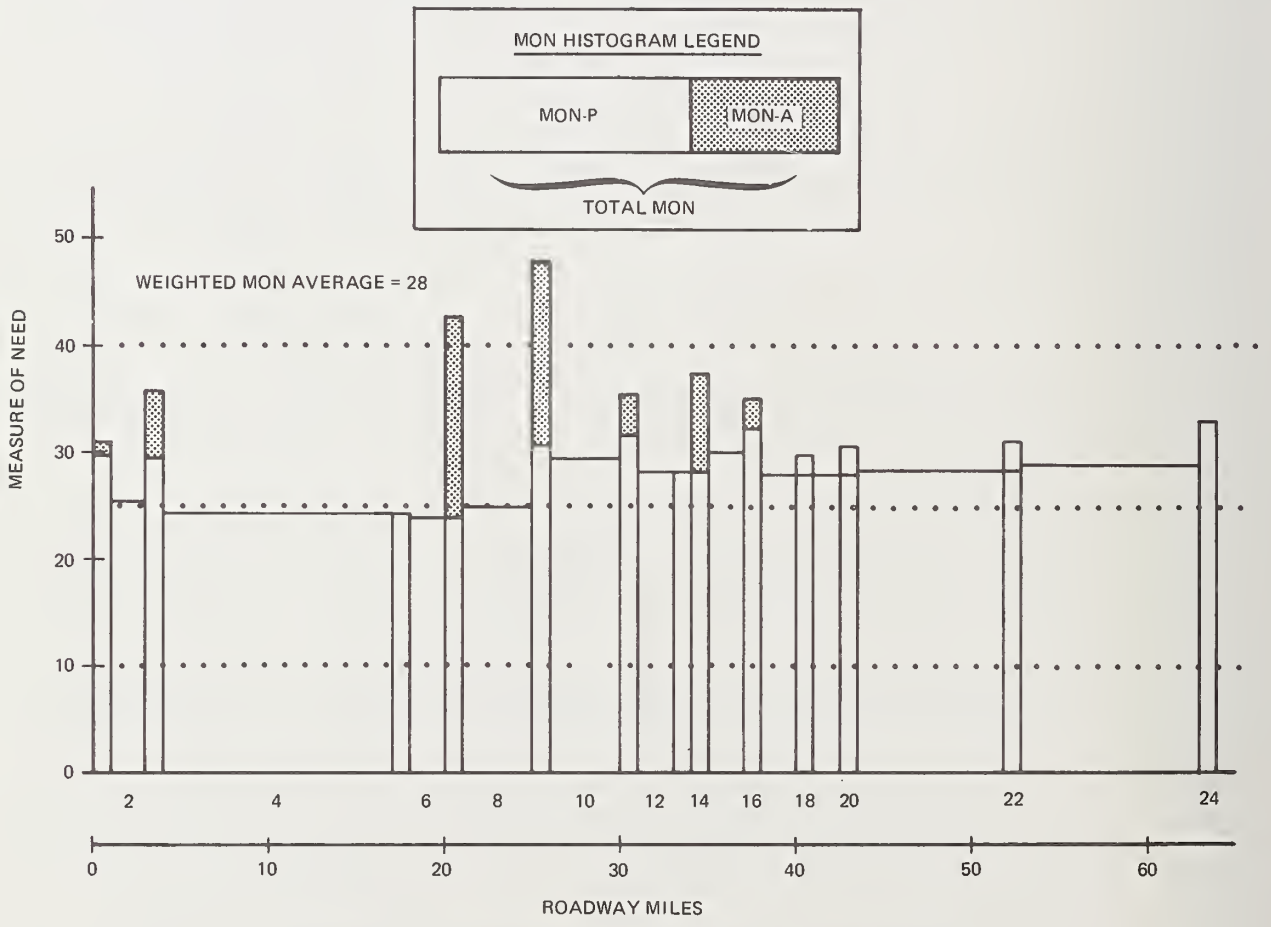


Figure E-7. Arizona System (I-10) - MON Histogram

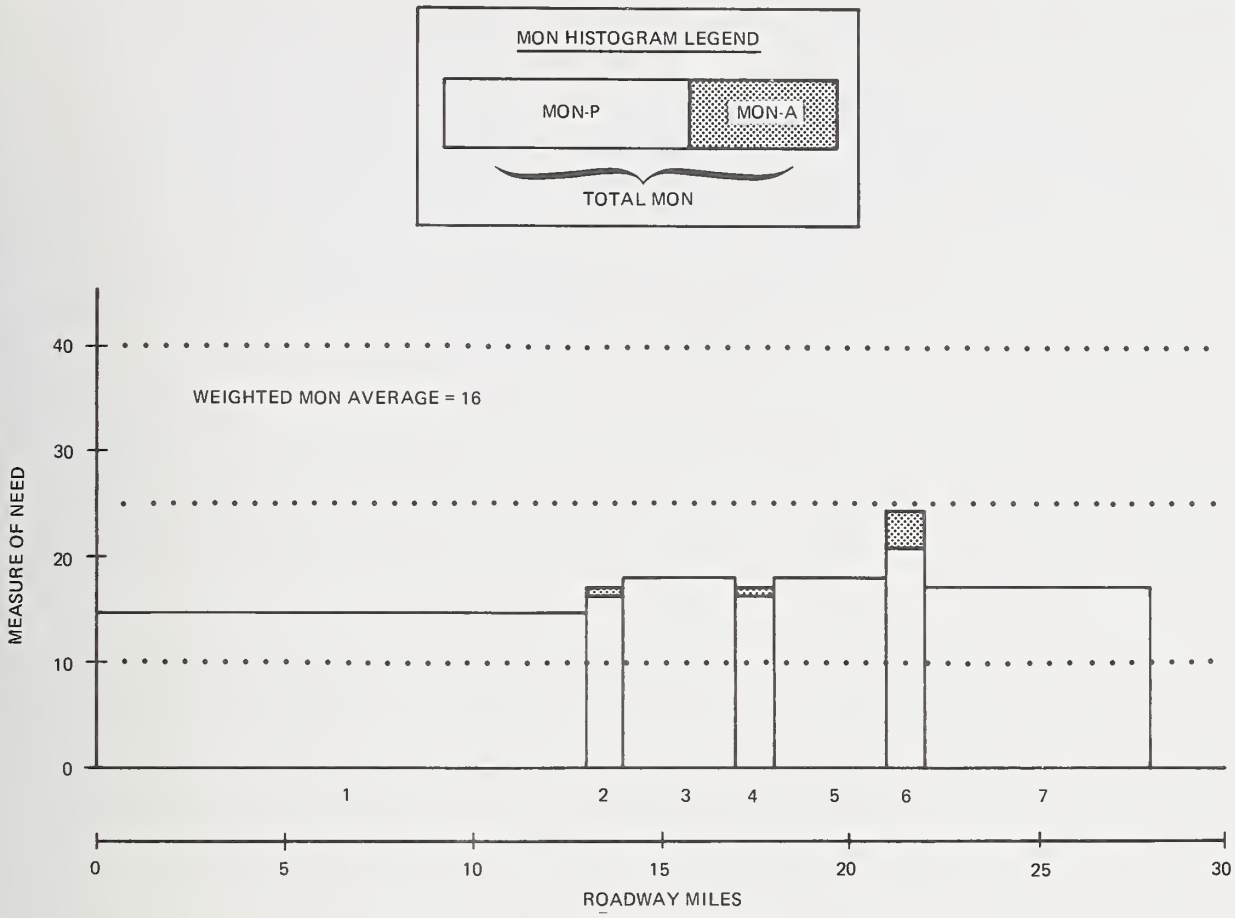


Figure E-8. Arizona System (I-8) - MON Histogram

in response to two severe multiple vehicle accidents on I-10 which took place in June 1970 and May 1971. Both accidents claimed eight fatalities.

The primary system objective is to reduce accidents due to reduced visibility from blowing dust. Secondary objectives are to satisfy public demand and educate the motorist in "what to do" when confronted with a dust storm.

b. PERFORMANCE

Since June 1976, the Arizona DOT has been operating a modified version of its warning system on Interstates 8 and 10. With this system, the changeable message signs alert the motorist to tune their car radios to one of the pre-selected commercial radio stations for dust storm alert messages. Arizona DOT has been in close contact with the local radio stations to solicit better cooperation to broadcast the dust storm alert messages. To date, the radio station performance on D/S alert messages has been very sporadic. This is due, in part, to the inability of the radio station personnel to comprehend from a distance the severity of a dust storm.

Educational presentations have been made by Arizona DOT to each of the involved radio stations.

The radio stations have made several complaints and have requested certain changes in the D/S alert format provided by Arizona DOT. In theory, a "canned" message is supposed to be transmitted once every ten minutes during the storm alert period. However, the station announcers are not content with the "canned" format and prefer to paraphrase the message at the required interval. This difference of opinion has led to a drop in the efficiency of maintaining the agreed-upon time interval for broadcasting the alert messages. After meeting with the involved radio stations, DOT agreed to the paraphrased message format.

A motorist survey was performed by Arizona to determine the effectiveness of the commercial radio station broadcasts. The survey revealed that 71% of the drivers sampled were tuned to the dust alert station and that the modified system provides timely warning 98% of the time, with no indication received from the motorists that they required more information. The surveyed motorists indicated that a definite advantage of the system is the information about "what to do" if caught in a dust storm.

The performance of the system signs has been generally satisfactory. Interviews with the State Police revealed that motorists have reacted favorably to the system signs. Arizona is presently exploring revisions to the control console at the police headquarters that will reduce the time required to activate the system signs. The present radio equipment at central allows for only one sign to be activated at a time. This can be a time consuming effort if all the system signs need to be activated. The contemplated revision would give the system operator the option to activate large groups of signs if the situation necessitated their activation.

To enhance the credibility and timeliness and reduce costs of the Dust Warning System, Arizona DOT is considering the possibility of reducing the number of signs in the field by half.

The system maintenance function is divided between two agencies. Arizona DOT is responsible for field maintenance of the system signs. The maintenance and reliability record of the signs has been satisfactory. The reliability of the system signs was recently increased by removing the separate circuit cards from the field sign control equipment and replacing them with state-of-the-art integrated circuit boards. The State Police assume maintenance responsibility for the control console at their Phoenix headquarters. The operational record of the control console radio equipment has been fair. This segregation of maintenance duties may contribute to lowering the system's overall performance level.

c. ECONOMIC JUSTIFICATION

A "Before" and "After" accident comparison study was made by Arizona DOT using two years and three months for each time period. There were 15 accidents in the "Before" period and 10 accidents in the "After" period. The conclusion reached was that this is not a statistically significant decrease.

There were 11 major dust storms in the "Before" period, 6 in the "After" period. The dust accident rate per million vehicles decreased from 4.31 before to 2.84 after, a 34% change in the dust accident rate for the system area. The number of people killed and injured per accident decreased from 0.53 killed/accident and 4.07 injured/accident to 0.20 killed/accident and 3.50 injured/accident. It is reasonable to assume that part of these reductions can be attributed to the existence of the Dust Warning System.

Appendix E-2
CALIFORNIA STATE ROUTE 91 SYSTEM

E2-1 SUMMARY

- Environmental Hazard: Dense Fog
- Site Location: Riverside County near Corona
- Facility: State Route 91, six and eight lane freeway, AADT = 70,000
- System Length: 20 miles (32.2 Km)
- System Elements: Raised pavement markers and truck-mounted variable message signs

E2-2 SYSTEM DESCRIPTION

During reduced visibility conditions, the California system utilizes passive and active techniques to advise and guide motorist on Route 91. Reflective raised pavement markers constitute the passive element of the system. Two types of raised pavement markers are used for roadway delineation along the 20 mile (32.2 Km) portion of Route 91. Acrylic cube corner reflector units provide delineation for nighttime visibility and ceramic button-type markers are used for daytime visibility. The pavement lines on Route 91 are formed by using a combination of reflectorized markers for nighttime visibility and ceramic markers for daytime visibility.

The truck-mounted variable message signs (VMS) are the active element of the system. The purpose of the signs is to provide advisory information to motorists during hazardous driving conditions due to fog. Weather forecasts and police patrol reports of visibility conditions on Route 91 are received at the highway operations control room in the district office. During a fog alert, the VMS trucks are dispatched to the problem areas. If the fog is localized, the trucks are positioned in advance of the fog area in order to advise motorists of the imminent hazardous driving conditions. In area-wide fogs, the positioning of the VMS trucks is left to the discretion of the experienced driver.

Two types of VMS trucks are used. The first type is configured with a 5-foot (1.5 m) square blank panel mounted in the rear of a small pick-up truck. (See Figure E-9.) Preprinted messages on velcro-backed canvas can be affixed to the panel. Typical messages used during fog conditions are "FOG-SLOW" and "REDUCE SPEED". The VMS truck also has a portable generator that is used to provide power for flood lights positioned at the base of the panel board for nighttime operation. The trucks are also used at times of normal visibility to control traffic during freeway incidents and construction work, and during special events.

The second type of VMS truck has a bulb matrix variable message sign panel mounted behind the truck cab. (See Figure E-10.) At the base of the sign panel

Figure E-9. Variable Message Sign Truck: Velcro Panel Type

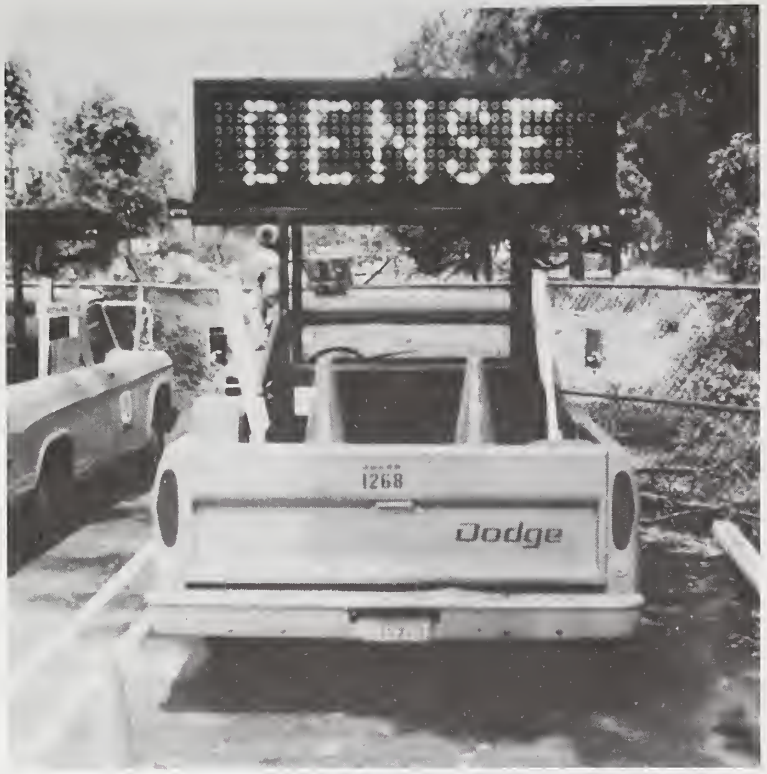


Figure E-10. Variable Message Sign Truck: Bulb Matrix Type

there is a gasoline generator that is used to power the sign bulbs and drive the sign panel erection mechanism. When the VMS truck is in transit, the sign panel is lowered to a horizontal position.

A solid state programmer unit which contains all the necessary controls for operating the sign panel is mounted under the dash in the truck cab. The programmer unit contains a solid state alphanumeric display that duplicates, and thus provides verification of, the actual message shown on the sign panel. Messages are entered by inserting a pre-taped cassette into a tape reader in the programmer unit.

Typical messages displayed on the sign panel during reduced visibility conditions are: "DENSE FOG AHEAD" and "FOG AHEAD 40 MPH". The two VMS trucks are also used for general traffic control during normal visibility conditions.

Caltrans is presently in the process of altering the sign panel on the Los Angeles based truck to increase the message capability from one 5-letter word per line to a 7-letter word. The trucks at San Bernardino were purchased with 7-letter capability. This will allow more precise messages to be displayed.

E2-3 SYSTEM COSTS AND UTILITY

The evaluation analysis for the California System is focused on its passive element, that is, passive roadway delineation provided by raised pavement markers and lane delineation markers. However, cost and utility figures for the variable message sign trucks were also developed.

a. COSTS

The implementation and maintenance costs for the California systems are shown in Tables E-5 and E-6.

TABLE E-5. CALIFORNIA DELINEATION SYSTEM COSTS

	Cost (1975)	Cost (1/7/77)
Implementation	$34,400	$ 39,000
Maintenance	6,060/yr.*	6,840/yr.
Total Present Worth of System	--	$119,000**

*Average annual cost after implementation.
**Includes the present worth of maintenance cost projected 15 years into the future from 1-1-77.

TABLE E-6. CALIFORNIA VARIABLE MESSAGE TRUCK COSTS

	Purchase Cost (1976)		Present Cost (1/7/77)	
	Velcro	Bulb Matrix	Velcro	Bulb Matrix
Implementation	$11.3K	$17.0K	$12K	$18.1K
Maintenance	-	-	$ 1.62K/yr	$ 2.0K/yr
Total Present Worth*	-	-	$23.3K	$31.7K

*Assumes 8 year truck/sign lifetime.

b. UTILITY

The individual utility ratings for the California systems, from Table E-10 are as follows:

- Delineation system utility = 349.3
- Velcro truck utility = 517.6
- Matrix truck utility = 502.2

The utility-to-cost ratios for the three systems are, therefore:

- Delineation: $\frac{U}{C} \times 10^5 = \frac{349.3}{\$119,000} \times 10^5 = 294$
- Velcro truck: $\frac{U}{C} \times 10^5 = \frac{517.6}{\$23,300} \times 10^5 = 2200$
- Matrix truck: $\frac{U}{C} \times 10^5 = \frac{502.2}{\$31,700} \times 10^5 = 1580$

Note that the low truck costs and their relatively reliable operation result in a very high utility-to-cost ratio. It is also worth noting however, that the utility model does not penalize systems which are mobile for the problems which arise due to traffic congestion, which may prevent the mobile unit from arriving at the problem site.

E2-4 MEASURE OF NEED

The RV accidents along Route 91 are displayed on the Baseline Data Map shown in Figure E-11. There are 10 MON Sections over the 20-mile (32.2 Km) length of Route 91. The largest concentration of RV accidents occurs in MON Sections 2, 3 and 5 which account for 82 percent of all the RV accidents.

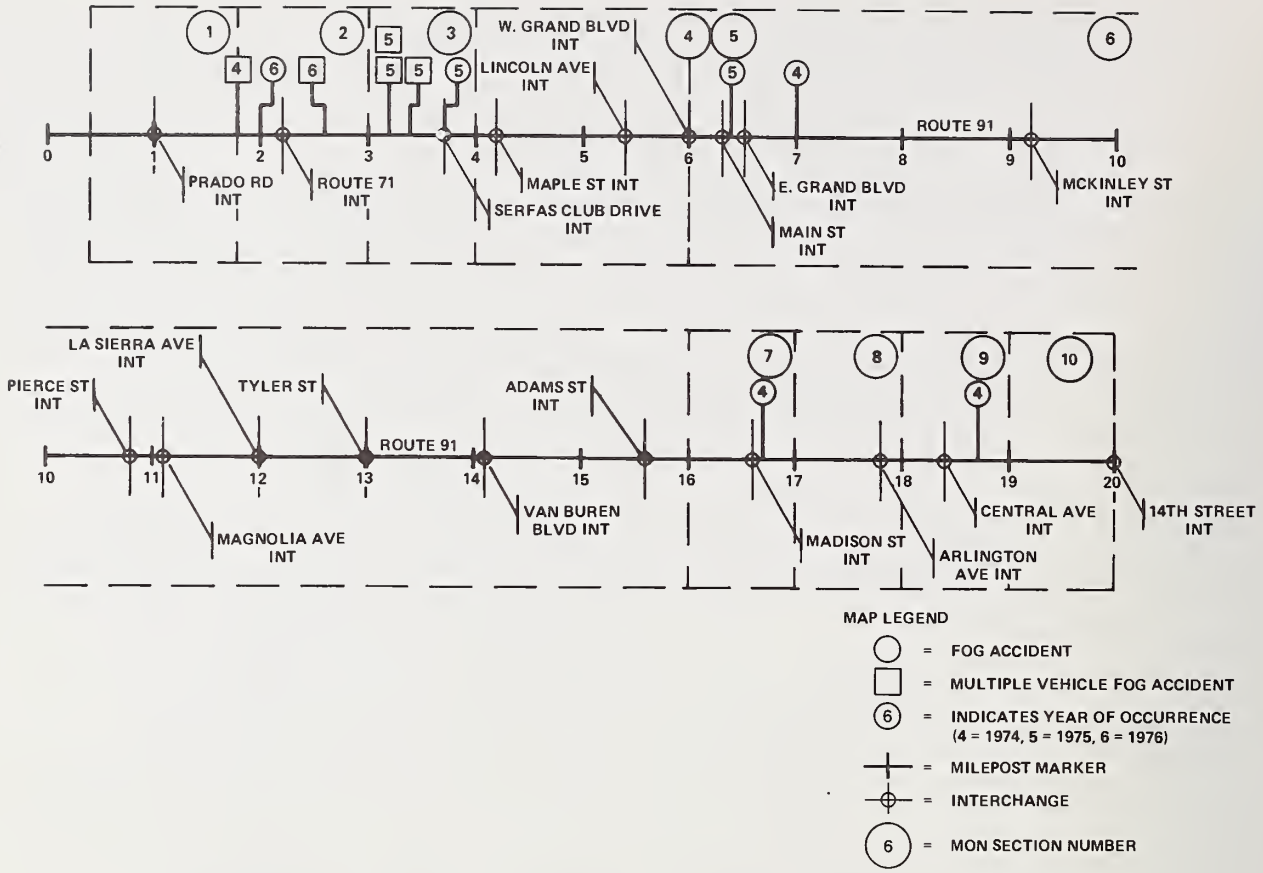


Figure E-11. California (Route 91) System Measure-of-Need MON Baseline Data Map

Table E-7 shows the input data used to compute the MON for each MON Section. The sections vary in length from one mile (1.61 Km) to a maximum of 8.8 miles (4.2 Km). The high AADT volumes on Route 91 place the California System into a Category V System. The accident history time period spans three years, from 1974 to 1976. There were no RV fatalities; however, six RV multiple vehicle accidents occurred during this time period. MON Sections 2 and 3 contain the most number of RV accidents. The total number of entrance and exit ramps is high because of the short spacing of interchanges along the 20-mile (32.2 Km) stretch of Route 91. The 30 annual RV days per year was estimated from the records obtained from the Riverside Airport Weather Monitoring Station which is in the general vicinity of Route 91. The 20-mile (32.2 Km) section of Route 91 is basically level and in grade and has a tangent alignment, therefore, low geometric index values were assigned.

The MON histogram for the California System is shown in Figure E-12. The potential portion of the MON is very high (averaging over 30) compared to the accident portion. This is obviously due to the high AADT's and RV frequency estimate, and the larger number of entrance and exit ramps spread over a relatively

TABLE E-7. CALIFORNIA MON INPUT DATA

CALIFORNIA ROUTE 91 FILE 3Ø REV1

#	LENGTH	AADT	YEARS	FATALITIES	MULTI VEH.	TOTAL	RAMPS RV	DAYS	GRADE	CURV
1	1.8	71900	3.0	Ø	Ø	Ø	4	30	1.00	1.00
2	1.2	68000	3.0	Ø	2	3	4	30	1.00	1.00
3	1.Ø	68000	3.0	Ø	3	4	4	30	1.00	1.00
4	2.3	68000	3.0	Ø	Ø	Ø	13	30	1.00	1.00
5	1.Ø	67000	3.0	Ø	Ø	2	6	30	1.00	1.00
6	8.8	73700	3.0	Ø	Ø	Ø	26	30	1.00	1.00
7	1.Ø	78400	3.0	Ø	Ø	1	4	30	1.00	1.00
8	1.Ø	79200	3.0	Ø	Ø	Ø	3	30	1.00	1.00
9	1.Ø	83000	3.0	Ø	Ø	1	5	30	1.00	1.00
1Ø	1.Ø	85000	3.0	Ø	Ø	Ø	2	30	1.00	1.00

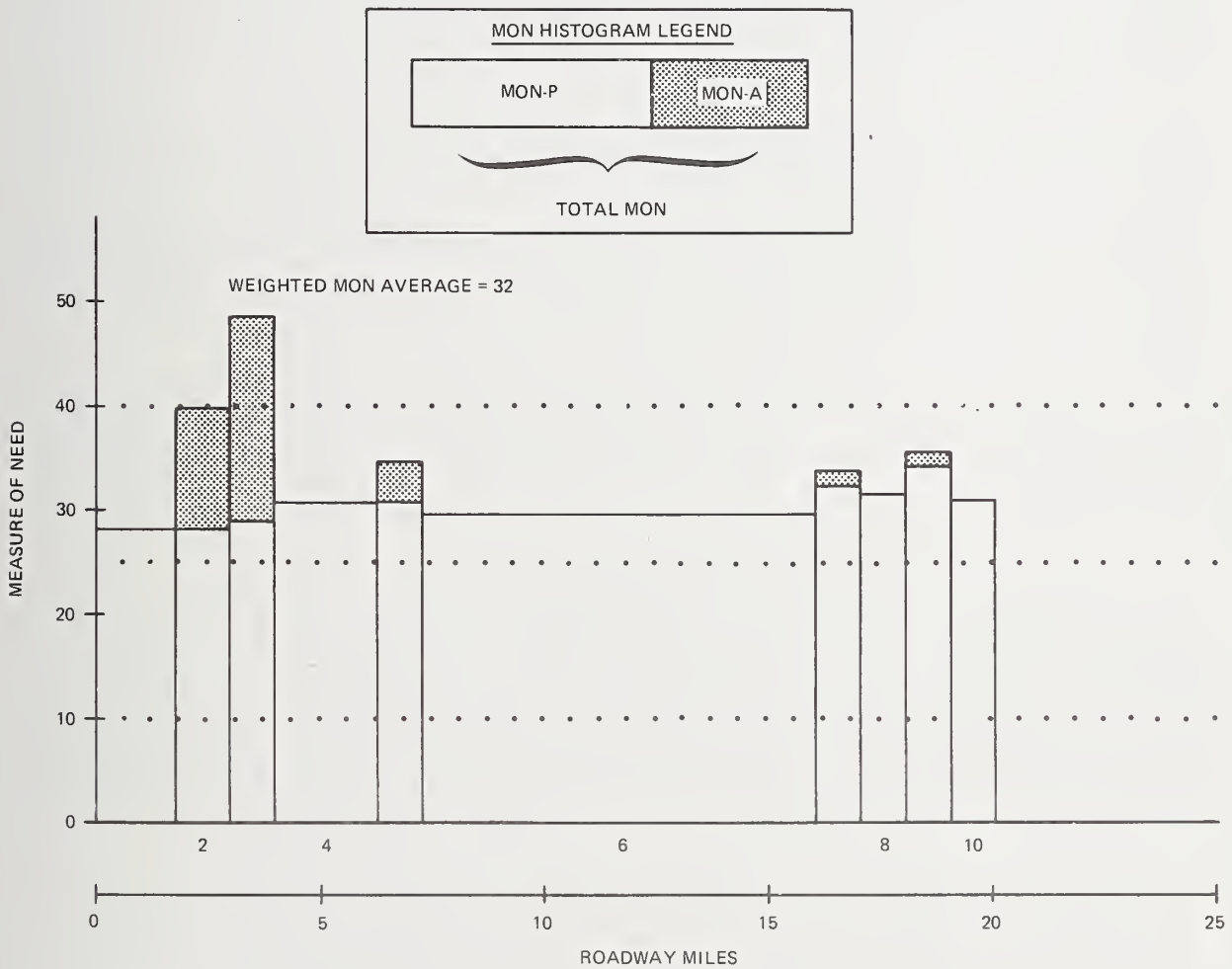


Figure E-12. California MON Histogram

short distance. MON Sections 2 and 3 are at or exceed the high threshold value. It can be inferred from this value that additional motorist guidance during RV conditions might be justified.

E2-5 DISCUSSION

a. OBJECTIVES

The primary objective of the California delineation system is to provide motorist guidance during all types of visibility and inclement weather conditions. The secondary objective is to delineate the roadway for motorists driving during fog conditions.

b. PERFORMANCE

The raised pavement markers along Route 91 have performed relatively well during nighttime RV conditions. However, these markers lose conspicuity under daylight RV conditions. In this case, the ceramic button-type markers are a somewhat more effective means of guiding the motorist due to their large circular appearance and white background color.

The maintenance experience of both types of markers have been favorable considering the fact that the Route 91 facility is subjected to heavy traffic volumes.

Truck-mounted signs have proven to be very useful, especially when traffic congestion is limited to local areas. Maintenance experience on the trucks has been uneventful for the most part. Problems with the electronic circuitry of the bulb matrix trucks have not been serious, and have been referred to the local manufacturer in the past.

Performance in very heavy congestion must be considered to fall off because of the problems in getting the trucks to the desired locations, unless they are posted nearby.

c. ECONOMIC JUSTIFICATION

Route 91 is a major facility in Orange County, California serving the travel demands of two large cities, Corona and Riverside. The heavy traffic volumes on this facility and the short interchange spacing, resulting in weaving movements, creates a particularly hazardous situation during RV conditions. RV accident experience has not been extraordinary, despite the potential. This, together with the fact that Route 91 is only one among many heavily traveled freeways in the fog area, may account for the use of techniques which seem to be limited in their capability to provide maximum credibility.

Appendix E-3
NEW JERSEY TURNPIKE SYSTEM

E3-1 SUMMARY

- Environmental Hazard: Dense fog
- Site Location: Central to northern New Jersey: Delaware Memorial Bridge to Ridgefield Park
- Facility: New Jersey Turnpike - Delaware Memorial Bridge to Interchange 9: Limited access highway Interchange 9 to 18: Dual-dual facility with inner and outer roadways (two-three limited access highways in each direction) Maximum AADT: 123, 900 between Int. 12 & 13
- System Length: 118 miles (189.9 Km)
- System Elements: Speed limit and hazard warning variable message signs throughout 118-mile length. Northern portion Interchange 9 to 18: Vehicle detectors, central and field processors, central control room with peripherals including map display and operators console and fog detectors (planned)

E3-2 SYSTEM DESCRIPTION

Variable message and variable speed limit signs are positioned throughout the entire length of the turnpike. The primary purpose of these signs to warn and advise motorists whenever a hazardous driving condition exists, the signs are also regulatory. One of the functional elements of these signs is their capability for providing motorists with guidance information during reduced visibility conditions.

The variable message (hazard warning) signs were installed in 1951 and are spaced the lesser of 5 miles (8.1 Km) or within one mile (1.6 Km) of each interchange. The signs are used to warn motorists of both non-RV and RV driving harzards. Each sign has the capability of displaying messages related to traffic congestion, accidents, construction work, and weather hazards (snow and ice). Example messages are: "REDUCE SPEED. ACCIDENT AHEAD" and "REDUCE SPEED. ICE AHEAD". The messages are displayed with a red neon tubing lettering arrangement. In addition, each sign can display this RV message "REDUCE SPEED - FOG AHEAD".

The variable speed limit signs were added in 1964-1966. These signs are a combination type employing neon tubing to display the normal speed limit advisory "55 MPH", and a bulb matrix array to indicate the reduced speed. The signs are capable of displaying speeds from 50 MPH (80.4 KPH) to 30 MPH (56.3 KPH) in increments of 5 MPH (8.0 KPH). Both sign types are controlled remotely from the Traffic Operations Center at the Turnpike Administration Building located in New

Brunswick. These signs can also be operated at the site. These signs are used in conjunction with the hazard warning signs during RV conditions. In most cases, a fog warning message on the variable message sign is accompanied with a reduction in the speed limit.

In the mid 60's, the heavily traveled northern end of the Turnpike from Interchange 9 to 18 was converted into a dual-dual facility with separate inner and outer roadways in each direction of travel. The inner and outer roadways consist of separate three lane limited access facilities. It is in this portion of the Turnpike where the fog problem is most severe. In this northern section of the Turnpike, there are many sites where the variable message and speed limit signs are positioned along side each other as shown in Figure E-13. Communication with the driver using this signing configuration is better because the motorist is told the type of hazard to be encountered, with an accompanying speed with which to proceed. Figure E-14 shows a typical NJTP sign site.

In late 1969, the Turnpike installed changeable message signs (rotating drum type) along the dual-dual portion of Turnpike for congestion and diversion control. This design enabled manual operation of the signs from the system control room.

Weather forecasts, which contain specific fog and snow advisories, are received three times a day from a private weather service, and are used for advanced alerting. The roadway is closed in sections for visibility of less than two delineators, or when in the opinion of State Police safe operation of vehicles cannot be maintained. The speed signs are set on the basis of the number of delineators visible, varying from 30 MPH (48.3 KPH) for 2 delineators to 55 MPH (80.4 KPH) for 11 to 14 delineators visible. The roadway is closed when no delineators are visible.

A traffic surveillance and control system has recently been installed on the dual-dual section of Turnpike (north of Interchange 9). The computerized system controls all the signs in the northern end and is used for congestion monitoring, diversion and incident control. Vehicle detectors installed in the roadway at half-mile (0.80 Km) intervals and speed traps at all interchanges provide the surveillance data for exercising control of the signs.

The surveillance and control system was not specifically designed for reduced visibility conditions, however, it does prove helpful for coping with these conditions. The system is capable of activating the hazard warning and diversion control signs automatically in addition to setting the advisory speed limits. However, these signs are currently manually operated for reduced visibility conditions.

Two computers are used to pre-process the data from the large number of vehicle detectors before the data are passed on to a separate sign control computer. This computer is centrally located in the NJTP administration building. A large map display and associated peripherals are part of the system. These include magnetic tape units, line printer, card reader, CRT data terminals and TTY. Figures E-15 and E-16 shows the map display and operation console inside the system control room.

Figure E-13. Typical NJ Turnpike Signing Site: Speed Warning and Speed Limit Signs

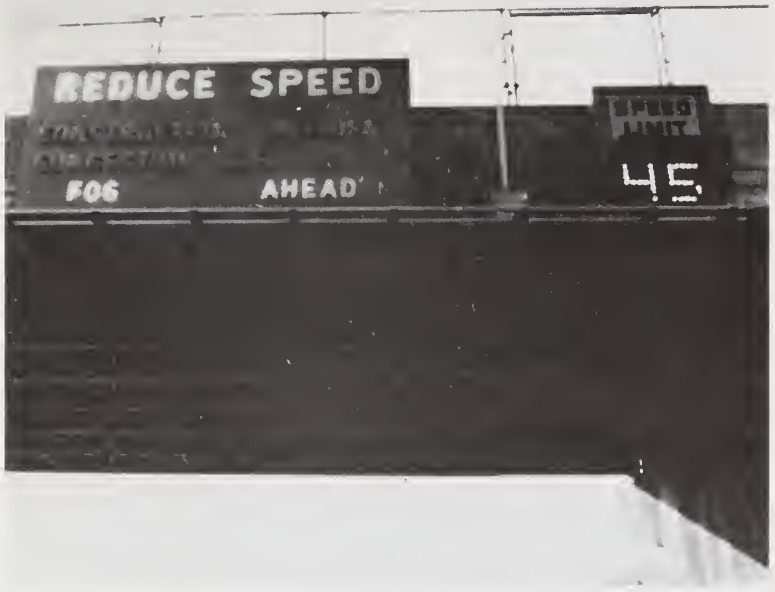


Figure E-14. NJ Turnpike Speed Limit and Speed Warning Signs

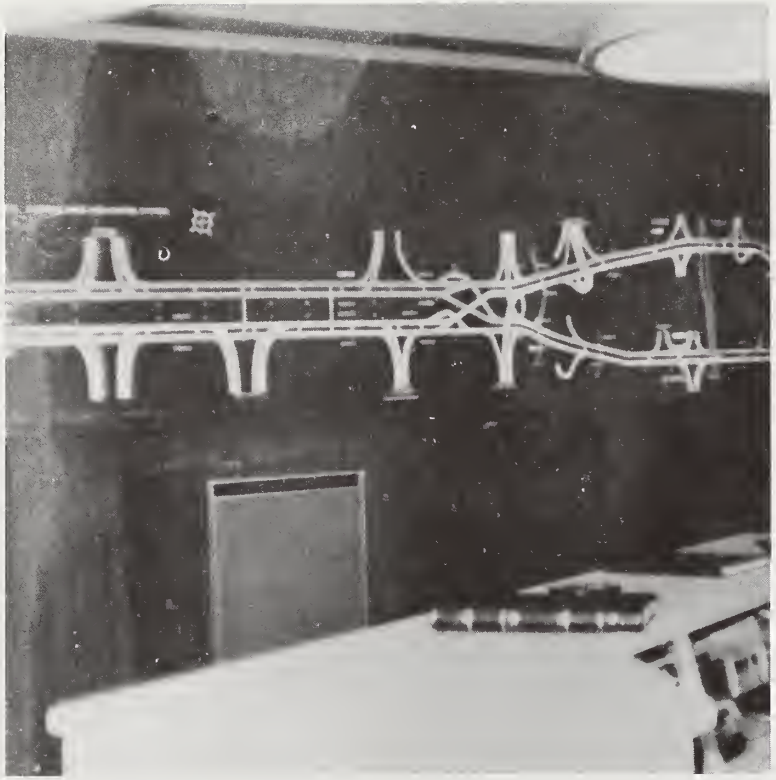


Figure E-15. NJ Turnpike Operator's Console and Map Display

Figure E-16. System Control Room (NJ Turnpike Administration Building)

The Turnpike Authority is about to undertake the installation of several fog detectors in the most consistently fog-prone section of the Turnpike's northern end. At first, the data from these detectors will be used to complement highway patrol surveillance data. The operation of the reduced visibility portion of the system will remain manual.

Eventually, however, it is planned to tie the fog detector data directly into the system so that fog advisories and speed limits signs will be set automatically.

E3-3 SYSTEM COSTS AND UTILITY

a. COSTS

Since the New Jersey Turnpike system was not specifically designed for reduced visibility conditions, the actual system costs could not be used for the cost-utility analysis. In order to arrive at a cost figure for the reduced visibility usage of the system, a portion of the total system cost was factored. The factor which was used was the fraction corresponding to the average number of reduced visibility days per year. The total system costs were multiplied by this factor to arrive at the RV element of the Turnpike system. The implementation, operation and maintenance costs for the factored RV element of the New Jersey Turnpike system are shown in Table E-8.

TABLE E-8. NEW JERSEY TURNPIKE: FACTORED SYSTEM COSTS

Item	Cost (Year Varies)	Cost (1-1-77)
Implementation	$520,000	$687,000
Operation & Maintenance	-	$ 12,400/year

The present worth of the factored RV element of the Turnpike system is $832,000. This figure includes the factored present worth of the operation and maintenance costs projected for 15 years into the future from 1-1-77.

b. UTILITY

Table E-9 shows the individual utility measures ratings for the New Jersey Turnpike system. The total system utility is 635.7, and the utility to cost ratio, using the present worth in dollars as the cost element is therefore:

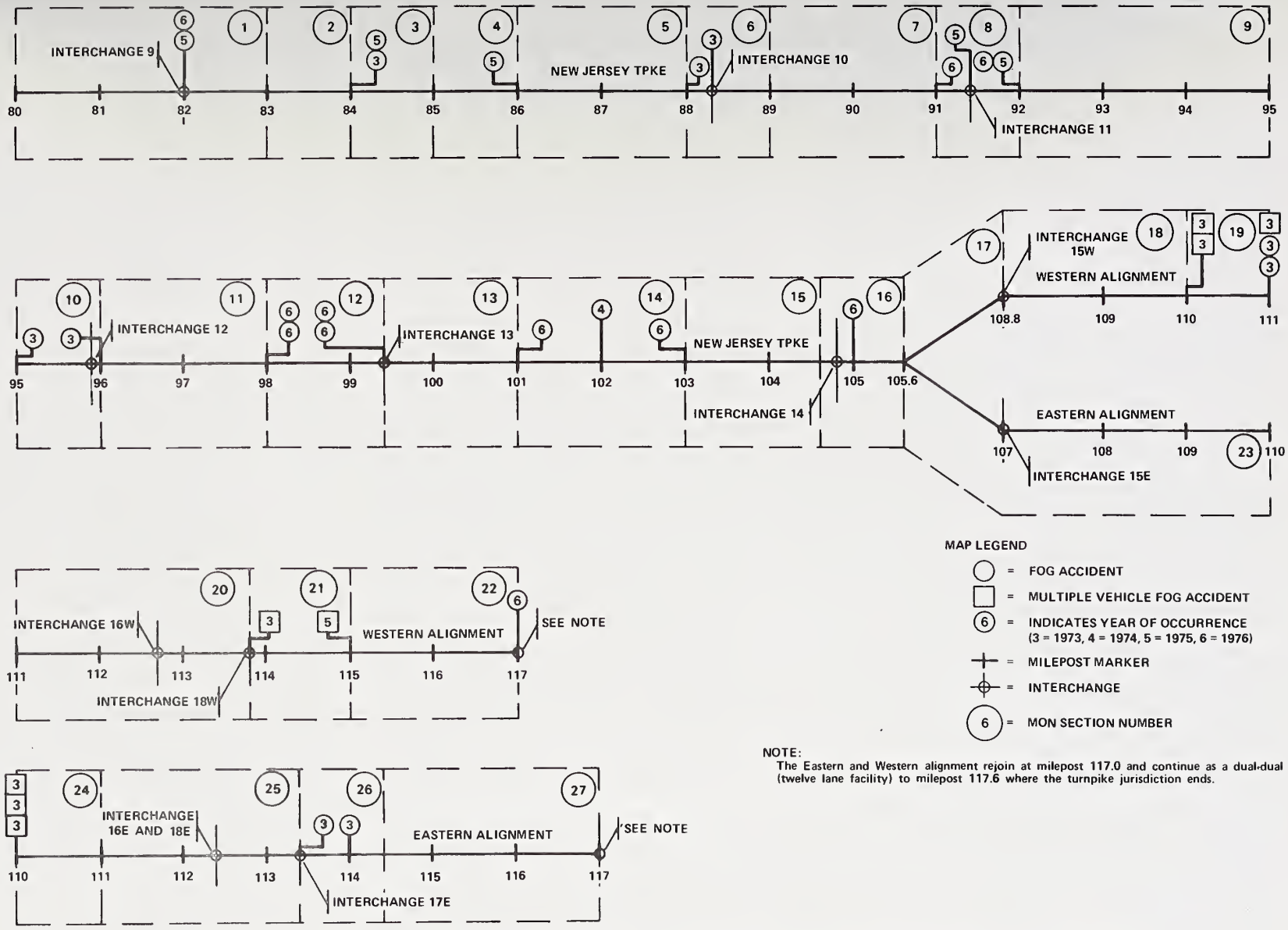
$$\frac{U}{C} \times 10^5 = \frac{635.7}{\$832,000} \times 10^5 = 76$$

E3-4 MEASURE-OF-NEED

The location of the fog-related accidents on the northern portion of the New Jersey Turnpike are displayed on the MON Baseline Data Map shown in Figure E-17. As can be seen in the figure, the Turnpike divides into an eastern and western

TABLE E-9. NEW JERSEY TURNPIKE - UTILITY RATINGS

Utility Measure	System Value	Comp.	Util.
I. ROADWAY OPERATION			
1. Reduce Accidents	19.2	6	115.2
2. Maintain H/S Level	12.8	6	76.8
II. SATISFY PUBLIC DEMAND			
1. Provide Credible A/W	12.6	6	75.6
2. Reduce Driver Stress	3.6	6	21.6
3. Public Reaction	1.8	6	10.8
III. RELIABILITY & MAINTAINABILITY			
1. Reliability	7.5	6.5	47.8
2. Preventive Maint. Reqts	3.7	6.5	24.0
3. Field Maint.	2.3	5.0	11.5
4. Central Maint.	1.5	6.5	9.8
IV. SYSTEM OPERATION			
1. Manual Override	3.9	8	31.2
2. Operating Complexity	3.9	7.5	29.2
3. Central Control Capab.	3.3	9.0	29.7
4. Backup Capability	1.9	8.0	15.2
V. MONITORING CAPABILITY			
1. Traffic Operation	4.5	8.0	36.0
2. System Function	4.5	7.5	33.8
VI. FLEXIBILITY			
1. Ease of Modification	3.6	3.0	10.8
2. Ease of Expansion	2.4	4.0	9.6
VII. SECONDARY USES			
1. Data Processing	2.0	7.0	14.0
2. Non-RV Mess. Info.	2.0	8.0	16.0
VIII. INSTALLATION DISRUPTION			
1. Service Disruption	1.5	5.5	8.2
2. Installation Complexity	0.8	5.5	4.4
3. Schedule Feasibility	0.7	5.0	3.5
	100.0		635.7



NOTE:
The Eastern and Western alignment rejoin at milepost 117.0 and continue as a dual-dual (twelve lane facility) to milepost 117.6 where the turnpike jurisdiction ends.

Figure E-17. New Jersey Turnpike System Measure-of-Need MON Baseline Data Map

alignment at the northern end. These portions of the Turnpike pass through marsh lands that are frequently in dense fog. There are 46.4 roadway miles (74.7 Km) in the northern portion of the Turnpike which includes both alignments, divided into a total of 27 MON sections. The RV accidents are evenly distributed between mile posts 81 and 105.6 where the Turnpike divides. The accident density is slightly greater in both the eastern and western alignments which are also more exposed to RV conditions than the roadway south of Milepost 105.6.

Table E-10 shows the MON input data for the Turnpike. The MON section lengths vary from one mile (1.6 Km) to 4.4 miles (7.1 Km). The AADT traffic volumes span both system categories IV and V. The MON values were obtained by computing MON's for both categories and computing the average values. The accident history time period covers the years from 1973 to 1976. In MON Section 19 there are five RV fatalities; this is the result of a multiple vehicle accident that involved 23 vehicles which occurred in 1973. The remaining RV fatalities also occurred on the separated alignment sections of the Turnpike. Similarly, all the multiple vehicle accidents occurred along the northern alignments. In terms of total RV accidents, the separated alignment sections account for 38% of all the RV accidents. MON Section 16, which contains the point at which the dual-dual roadways diverge has the largest number of entrance and exit ramps.

The estimate of the average annual RV days was derived from the Turnpike records of speed limit reductions due to RV conditions. These records were detailed enough to estimate the RV frequency on a section by section basis. The RV estimates revealed that the RV frequency increases from south to north on the Turnpike, and the maximum is reached on the separated alignment portions. In MON Sections 13 thru 18, the Turnpike is primarily on a viaduct and has narrow shoulder widths. Therefore, the grade and curvature indices were assigned higher weighting values.

The MON histogram for the New Jersey Turnpike system is shown in Figure E-18. The potential portion of the MON varies from a low of 11 to a high of 25. Even though the traffic volumes are high, this range is relatively small compared to the other sample systems. The histogram shows that the accident portion of the MON is greatest in Section 19 and 24. In addition, the remaining MON sections of the eastern and western alignments also have relatively high MON accident portion values. Collectively, the weighted MON average for the Turnpike is 20, below the medium threshold value, although portions of the system have MON's above this value.

E3-5 DISCUSSION

a. OBJECTIVES

The New Jersey Turnpike is a major north-south facility serving one of the most urbanized areas in the country. The primary objective of the Turnpike system is to safeguard public safety through congestion monitoring, diversion and incident control, and by motorist advisories during inclement weather conditions. A secondary objective is to provide motorists with information during periods of reduced visibility in the form of hazard warning messages and speed limit reductions.

TABLE E-10. NEW JERSEY TURNPIKE - MON INPUT DATA

NEW JERSEY TURNPIKE FILE 31 REVØ4

	#	LENGTH	AADT	YEARS	FATALITIES	MULTI VEH.	TOTAL	RAMPS RV	DAYS	GRADE	CURV
	1	1.Ø	84ØØØ	4.Ø	Ø	Ø	2	8	6	2.ØØ	2.ØØ
	2	1.Ø	84ØØØ	4.Ø	Ø	Ø	Ø	Ø	6	2.ØØ	2.ØØ
	3	1.Ø	84ØØØ	4.Ø	Ø	Ø	2	Ø	6	2.ØØ	2.ØØ
	4	1.Ø	84ØØØ	4.Ø	Ø	Ø	1	Ø	6	2.ØØ	2.ØØ
	5	2.Ø	84ØØØ	4.Ø	Ø	Ø	Ø	Ø	6	2.ØØ	2.ØØ
	6	1.Ø	84ØØØ	4.Ø	Ø	Ø	2	8	6	2.ØØ	2.ØØ
	7	2.Ø	921ØØ	4.Ø	Ø	Ø	Ø	Ø	6	2.ØØ	2.ØØ
	8	1.Ø	921ØØ	4.Ø	Ø	Ø	4	8	6	2.ØØ	2.ØØ
	9	3.Ø	116ØØØ	4.Ø	Ø	Ø	Ø	Ø	6	2.ØØ	2.ØØ
	1Ø	1.Ø	116ØØØ	4.Ø	Ø	Ø	2	8	6	2.ØØ	2.ØØ
	11	2.Ø	123ØØØ	4.Ø	Ø	Ø	Ø	Ø	8	2.ØØ	2.ØØ
	12	1.4	123ØØØ	4.Ø	Ø	Ø	4	8	8	2.ØØ	2.ØØ
	13	1.6	111ØØØ	4.Ø	Ø	Ø	Ø	Ø	8	5.ØØ	3.ØØ
	14	2.Ø	111ØØØ	4.Ø	Ø	Ø	3	Ø	9	5.ØØ	3.ØØ
	15	1.6	111ØØØ	4.Ø	Ø	Ø	Ø	Ø	9	4.ØØ	3.ØØ
	16	1.Ø	1Ø87ØØ	4.Ø	Ø	Ø	1	16	9	4.ØØ	4.ØØ
	17	3.2	572ØØ	4.Ø	Ø	Ø	Ø	4	9	5.ØØ	3.ØØ
	18	1.2	585ØØ	4.Ø	Ø	Ø	Ø	Ø	1Ø	5.ØØ	3.ØØ
	19	1.Ø	585ØØ	4.Ø	5	3	5	Ø	1Ø	2.ØØ	2.ØØ
WA*	2Ø	2.8	524ØØ	4.Ø	Ø	Ø	Ø	8	1Ø	2.ØØ	2.ØØ
	21	1.2	43ØØØ	4.Ø	1	1	2	Ø	1Ø	2.ØØ	2.ØØ
	22	2.Ø	43ØØØ	4.Ø	Ø	Ø	1	4	1Ø	2.ØØ	2.ØØ
	23	4.4	53ØØØ	4.Ø	Ø	Ø	Ø	4	1Ø	5.ØØ	3.ØØ
	24	1.Ø	537ØØ	4.Ø	2	3	3	Ø	1Ø	2.ØØ	2.ØØ
EA*	25	2.4	331ØØ	4.Ø	Ø	Ø	Ø	8	1Ø	2.ØØ	2.ØØ
	26	1.Ø	412ØØ	4.Ø	Ø	Ø	2	Ø	1Ø	2.ØØ	2.ØØ
	27	2.6	412ØØ	4.Ø	Ø	Ø	Ø	4	1Ø	2.ØØ	2.ØØ

* WA = WESTERN ALIGNMENT

EA = EASTERN ALIGNMENT

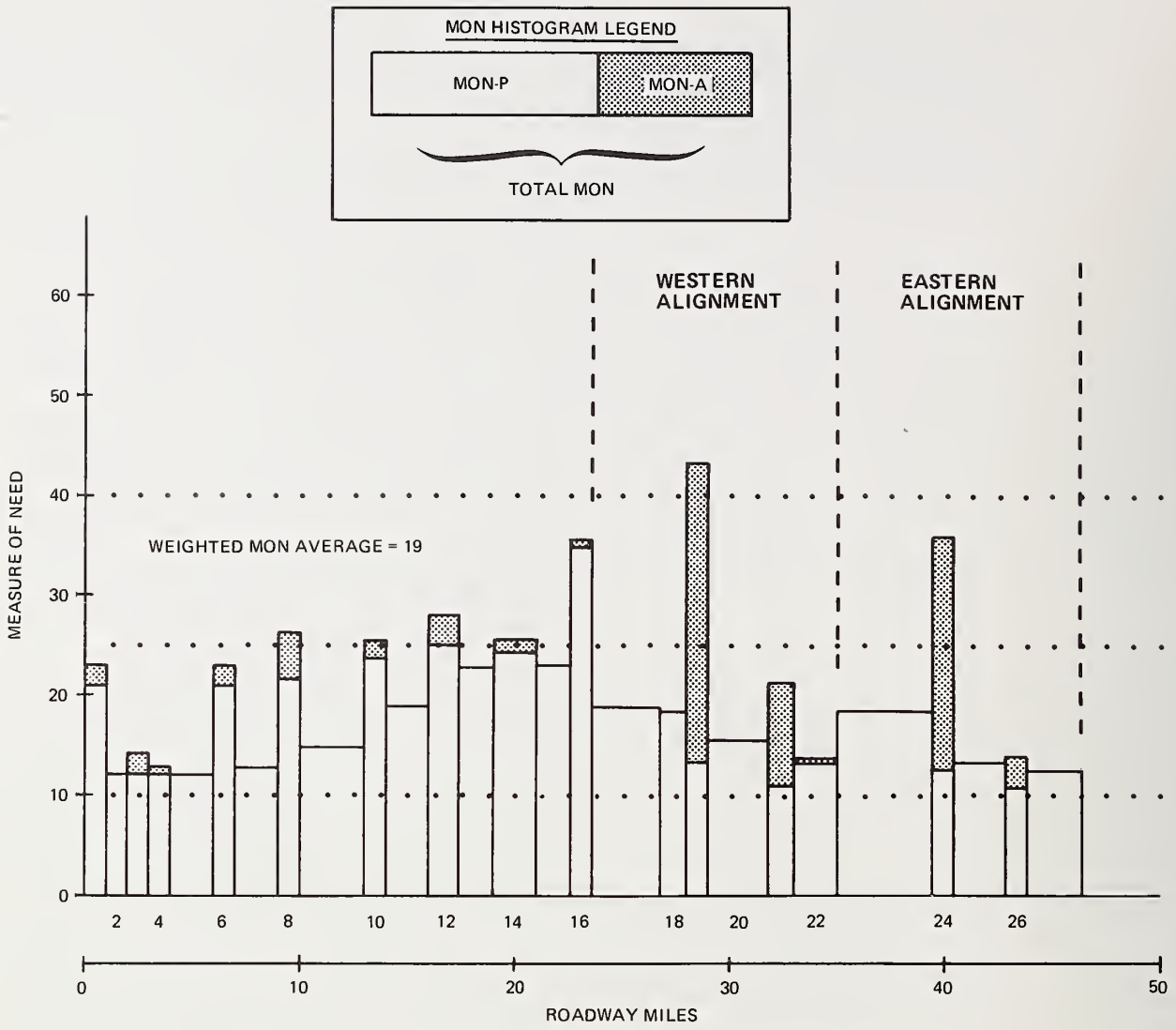


Figure E-18. New Jersey Turnpike - MON Histogram

b. PERFORMANCE

Since the Turnpike is a heavily traveled roadway, the potential for vehicle conflict during reduced visibility conditions is heightened; and in some cases it becomes extremely dangerous. The system, through the hazard warning messages and speed limit reduction, has been effective in operating the facility safely. The automatic vehicle surveillance system has shown reasonable adherence to the posted speed limits. Interviews with the State Police revealed that motorists view the system as being credible and helpful.

The traffic surveillance and control system equipment has performed well with only a few minor problems. The maintenance of the variable message and speed limit signs has been favorable.

c. ECONOMIC JUSTIFICATION

The primary justification of the New Jersey Turnpike system is that the highest possible level of service on the facility must be maintained for the motoring public. In addition to operating a safe facility, the system has been beneficial to motorists during reduced visibility conditions. Since the system was installed there has been a reduction in the number of RV related accidents, although it is not clear whether this is significant, since the number of RV days has varied considerably from year to year.

Appendix E-4
OREGON: I-5 FOG WARNING SYSTEM

E4-1 SUMMARY

- State: Oregon
- Environmental Hazard: Dense fog
- Site Location: North Albany
- Facility: Interstate 5; limited access divided highway two lanes each direction; AADT = 25,200
- System Length: 6.4 Miles (10.3 Km)
- System Elements: Neon type variable message signs, fog detector, vehicle detectors and mini-computer with display map

E4-2 SYSTEM DESCRIPTION

The fog warning system on Interstate 5 was installed as a research project in November 1968 in cooperation with the Federal Highway Administration, primarily in response to a series of chain-reaction collisions during a heavy fog in March of 1968. The system is 6.4 miles (10.3 Km) long, with three signs in each direction. The variable message signs are spaced from one to two miles (1.6 to 3.2 Km) apart. The northbound and the southbound signs are offset; that is, the northernmost of the northbound signs is slightly south of the southernmost southbound sign. This is done to provide advance warning, and also to conform better to the fog accident pattern history. The signs can be individually controlled either from the system police office building at the south end of the area or at the sign location. Normally, the signs are controlled from the state police office, based on radio reports from officers on patrol.

A backscatter type fog detector was originally installed to provide research data, but is not presently being used as a control device. When energized, the signs display "SLOW" and have the option of displaying the words "WRECK" and/or "FOG". (See Figure E-19.) They also display an advisory speed message with speeds from 10 to 50 mph (16.1 to 80.5 Km per hour) in steps of 10 mph (16.6 Km per hour). All letters and numerals are formed with high-intensity red neon tubing. No formal criteria have been established for energizing the signs or setting the speeds; the police officers use their best judgement. Credibility is kept high by energizing the signs only when required and restoring them to normal as soon as possible.

Associated with the variable message signs, twenty inductive-loop speed traps have been installed; one trap in each lane, just before each sign, and one in each lane of each direction at both ends of the fog area. A DEC mini-computer at the state police office (Figure E-20) is used with the loop detectors to process speed

Figure E-19. Oregon Variable Message Sign

Figure E-20. Oregon System - Research System Computer

and headway data. The loop detectors were installed as a research tool in order to be able to assess the effect of the signs and the speed setting on traffic behavior in fog. They are not used to control the variable message signs.

FDM communications on overhead leased lines are used to control the signs and to bring back the detector data. One line goes to each sign location and a maximum of seven signals are multiplexed onto each line.

The sign control panel at police headquarters consists of a bank of manually operated switches hard-wired to the communications. (See Figure E-21.) The signs can also be controlled by means of toggle switches in roadside cabinets at the sign locations.

E4-3 SYSTEM COSTS AND UTILITY

a. COSTS

Implementation, operation and maintenance costs for the Oregon sign control system are shown in Table E-11. The present worth of the system is $287,600, which includes the present worth of the maintenance and operation costs projected 15 years into the future from 1/1/77. These figures do not include the implementation, maintenance or operation costs of the research system, because the latter is not used to control the signs.

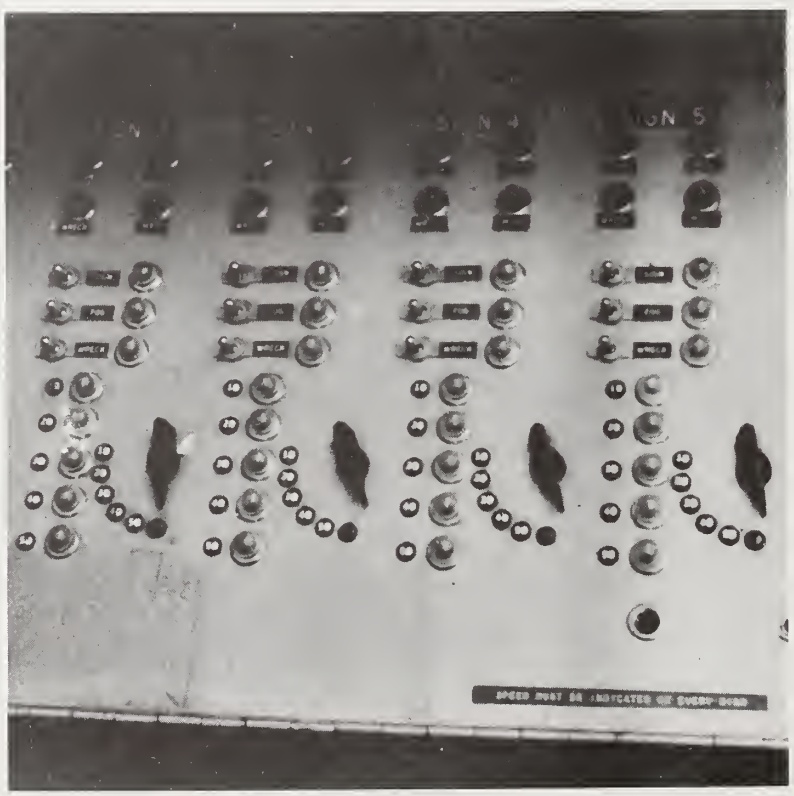


Figure E-21. Oregon Variable Message Sign Control Panel

TABLE E-11. OREGON SYSTEM COSTS

Item	Cost (1968)	Cost (1-1-77)
Implementation	$151,000	$263,500
Operation		
Leased Lines	-	1,130/yr
Power	-	370/yr
Maintenance	-	560/yr

b. UTILITY

Table E-12 shows the individual utility measure ratings for the Oregon variable message sign control system. The total system utility is 591.7 and the utility-to-cost ratio, using the present worth in dollars as the cost element is, therefore:

$$\frac{U}{C} \times 10^5 = \frac{591.7}{\$287,600} \times 10^5 = 206$$

TABLE E-12. OREGON SYSTEM - UTILITY RATINGS

	Utility Measure	System Value	Comp.	Util.
I.	ROADWAY OPERATION			
	1. Reduce Accidents	19.2	7	134.4
	2. Maintain H/S Level	12.8	5.5	70.4
II.	SATISFY PUBLIC DEMAND			
	1. Provide Credible A/W	12.6	7.5	94.5
	2. Reduce Driver Stress	3.6	5.5	19.8
	3. Public Reaction	1.8	7.5	13.5
III.	RELIABILITY & MAINTAINABILITY			
	1. Reliability	7.5	8	60.0
	2. Preventive Maint. Reqts	3.7	8	29.6
	3. Field Maint.	2.3	8	18.4
	4. Central Maint.	1.5	8	12.0
IV.	SYSTEM OPERATION			
	1. Manual Override	3.9	0	0
	2. Operating Complexity	3.9	8	31.2
	3. Central Control Capab.	3.3	8	26.4
	4. Backup Capability	1.9	7.5	14.3

Table E-12. Oregon System - Utility Ratings (Continued)

Utility Measure	System Value	Comp.	Util.
V. MONITORING CAPABILITY			
1. Traffic Operation	4.5	0	0
2. System Function	4.5	4	18.0
VI. FLEXIBILITY			
1. Ease of Modification	3.6	3	10.8
2. Ease of Expansion	2.4	3	7.2
VII. SECONDARY USES			
1. Data Processing	2.0	0	0
2. Non-RV Mess. Info.	2.0	5.5	11.0
VIII. INSTALLATION DISRUPTION			
1. Service Disruption	1.5	6.5	9.7
2. Installation Complexity	0.8	7	5.6
3. Schedule Feasibility	0.7	7	4.9
	100.0		591.7

E4-4 SYSTEM MEASURE-OF-NEED

The MON Baseline Data Map for the Oregon system is shown in Figure E-22. The largest concentration of RV accidents is in MON sections 4 and 5 which span a length of two miles (3.2 Km). In the remaining MON sections, the RV accident density is relatively low. The MON input data used for computing the MON is shown in Table E-13. The AADT volumes are just above 25,000 and, therefore, the Oregon System falls into system category number III. The accident history data spans the years from 1964 to 1968, the year the system was installed. MON Section 5 has the worst RV accident frequency with a total of 15 accidents. Due to the lack of detailed RV weather data, the RV frequency of occurrence was estimated to be the same for all the MON sections. The figure used was 45 RV days per year, and was derived from conversations with highway personnel and the State Police who frequently patrol the system site. The 6.4 mile (10.3 Km) highway site is fairly level and tangent, therefore, low geometric index rankings were assigned.

The results of the MON computation are presented in Figure E-23. The potential portion of the MON is basically the same for each MON section. As to be expected, MON Sections 4 and 5 display the highest accident portion values. Sections 4, 5, and 6 in this order have the highest MON values, and exceed high threshold value (MON = 40). The weighted MON average is 44, which strongly supports the implementation of the Oregon System.

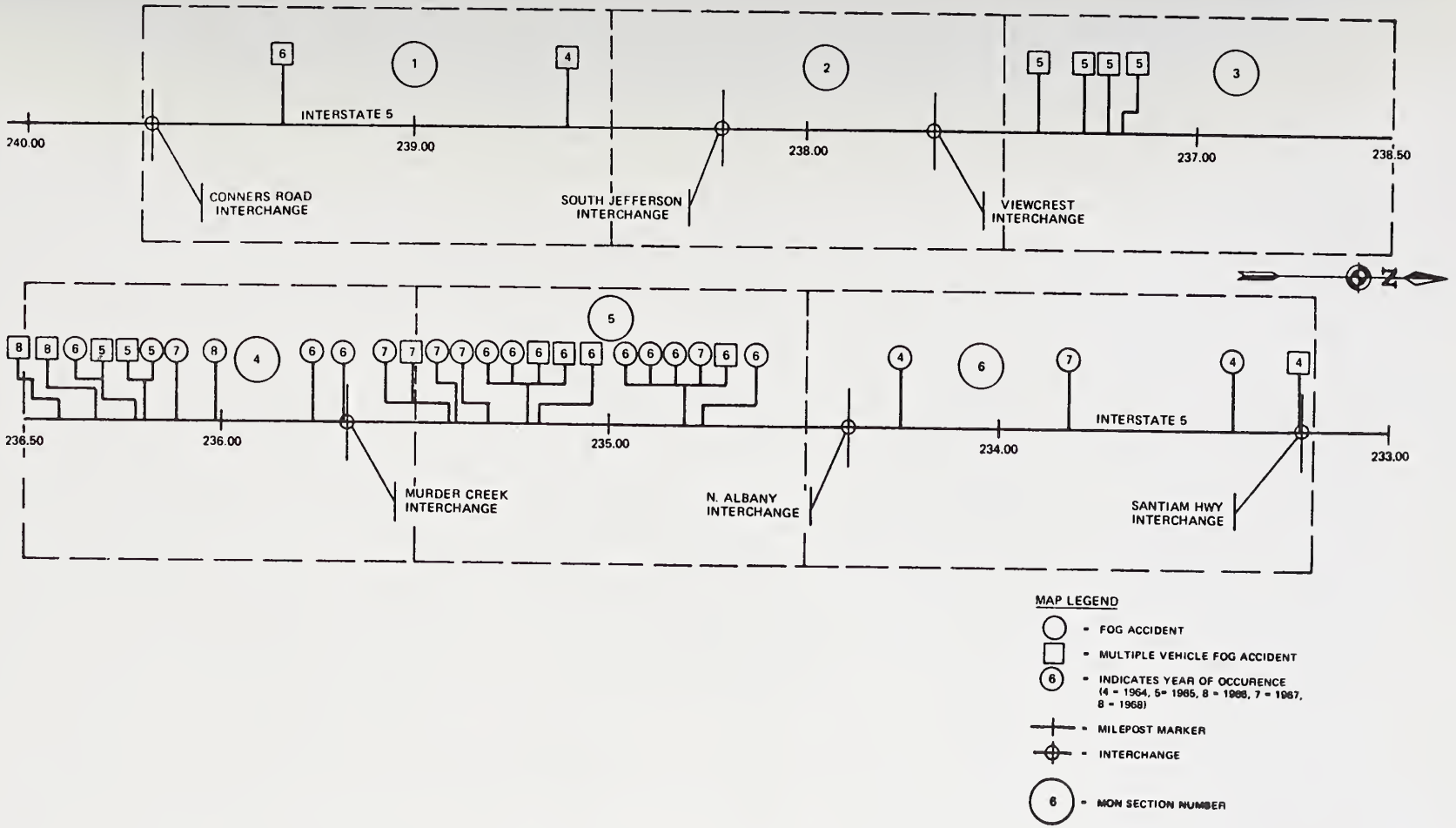


Figure E-22. Oregon MON Baseline Data Map

TABLE E-13. OREGON MON INPUT DATA

OREGON I-5 FILE 2Ø REV1

#	LENGTH	AADT	YEARS	FATALITIES	MULTI VEH.	TOTAL	RAMPS RV	DAYS	GRADE	CURV
1	1.2	246ØØ	5.Ø	Ø	2	2	4	45	1.ØØ	1.ØØ
2	1.Ø	262ØØ	5.Ø	Ø	Ø	Ø	7	45	1.ØØ	1.ØØ
3	1.Ø	261ØØ	5.Ø	Ø	4	4	Ø	45	1.ØØ	1.ØØ
4	1.Ø	263ØØ	5.Ø	3	4	1Ø	4	45	2.ØØ	1.ØØ
5	1.Ø	27ØØØ	5.Ø	1	5	15	Ø	45	2.ØØ	1.ØØ
6	1.3	2Ø9ØØ	5.Ø	1	1	4	8	45	1.ØØ	1.ØØ

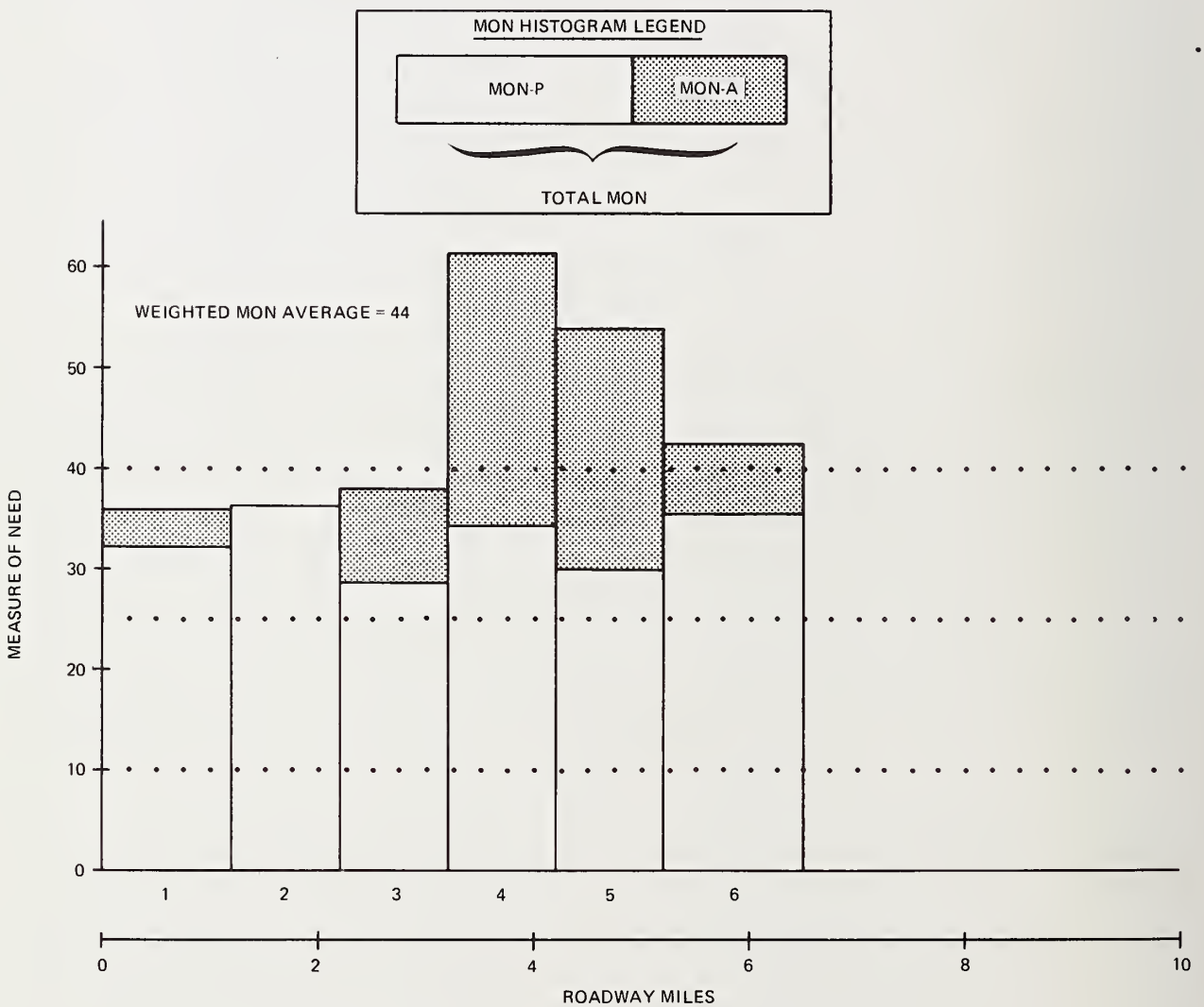


Figure E-23. Oregon - MON Histogram

E4-5 DISCUSSION

a. OBJECTIVES

The Oregon RV system was implemented in November 1968. It was primarily in response to a severe chain-reaction series of collisions which took place in March of 1968, involving 44 vehicles.

The primary system objective was to reduce the probability of further accidents of this type. A secondary objective was to satisfy public demand. Assuming the system to be required for these reasons, it was desired to provide it with additional flexibility - beyond that required for safety in reduced visibility, in the form of traffic hazard advisory messages.

b. PERFORMANCE

There have been no chain-reaction collisions since the 1968 occurrence. The accident record on the I-5 system shows what appears to be a significant improvement, despite the fact that the average number of reduced visibility days has not changed substantially over the period of observation. Thus, up to the present time, the system seems to have achieved its primary objective. This conclusion must be qualified by the observation that major chain-reaction collisions are very rare events in any case.

Credibility has been good because much emphasis has been placed on frequent and accurate patrol reports during reduced visibility. State Police had the opportunity to contribute to the conceptual design of the system and to the selection of messages for the signs. Thus, motivation to maintain good system performance is high.

Performance in a technical sense has been generally satisfactory. However, there have been occasions when the system failed to function when turned on after a long period of disuse. Periodic manual checks of the system equipment have helped, but this test function could be performed more easily and frequently if automation is introduced into the system.

The large neon signs have high visibility even in dense fog, and have had a very good maintenance record. The main source of problems has been the tone communications equipment, in which component failures have been fairly common. Service on the leased telephone lines has not been good and open circuits are common.

Applying the results of experience with the system, operations personnel feel that the major change they would make in system design is to increase sign flexibility; perhaps through the use of bulb or disk matrix signs with more sophisticated sign controllers. More consideration would also be given to the use of vehicle detectors to help in setting speed advisory signs.

c. ECONOMIC JUSTIFICATION

The accident experience since November 15, 1968, has been extremely favorable. There have been no chain-reaction type collisions, or any serious type of motor vehicle accidents during the periods of limited visibility when the signs have been in use. One accident, on December 18, 1970, was originally attributed to fog but subsequent investigation revealed it was due to ice and/or freezing fog.

Appendix E-5
VIRGINIA: I-64 FOG WARNING & GUIDANCE SYSTEM

E5-1 SUMMARY

- State: Virginia
- Environmental Hazard: Dense fog
- Site Location: Central Virginia, west of Charlottesville
- Facility: Interstate I-64, four lane limited access divided highway, AADT = 9,000
- System Length: 5.8 miles (9.3 Km)
- System Elements: Fixed advanced warning signs, pavement inset lights, fog detectors, raised reflectorized pavement markers, variable speed sign and low-level lamps for ramp illumination

E5-2 SYSTEM DESCRIPTION

The portion of Interstate 64 which crosses Afton Mountain in western Virginia is often engulfed in fog due to a low-lying cloud cover. A history of fog accidents in this area has led the Virginia Department of Highways and Transportation (VDHT) to install a reduced visibility guidance (RVG) system to aid motorists during periods of fog. The system was installed between May 15, 1974 and March 15, 1976, on a 5.8 mile (9.3 Km) section of I-64. The elements of the system are pavement inset (airport-type) lights, ramp illumination lights, fog detectors, advance warning signs and an experimental variable speed sign.

The basic elements of the system are 841 airport-type pavement inset lights. The lights are installed on each side of the roadway for westbound and eastbound traffic. They are mounted flush with the pavement and are spaced 200 feet (61 m) apart on straight sections of the road and 100 feet (30.5 m) apart on curved sections. In areas where it is inconvenient to run electrical cables for the inset lights, raised reflectorized pavement markers are substituted. The type of pavement inset light and raised pavement marker used on the Virginia system is shown in Figure E-24. The inset lights are controlled from a remote central control building located near an exit ramp near the western end of the guidance system which receives visibility data from roadside visibility detectors (Figure E-25).

No inset lights are installed on the highway bridges due to the difficulty involved and a reluctance to cut deeply into the bridge surface. Instead, raised reflectorized markers were installed in the pavement on 10-foot (3.04 m) centers. These markers are also installed in the gore areas on the entrance and exit ramps.

Figure E-24. Virginia Pavement Inset Light and Raised Pavement Marker

Figure E-25. Virginia System Roadside Visibility Detector

Study of the fog pattern indicated that the system could be effectively divided into three sections: one large section on top of the mountain, at the center of the system; and two shorter sections, one on each side of the mountain. This reduces the number of occasions on which the entire length of lights needs to be on simultaneously. The three sections are contiguous and are controlled separately by automatic fog detectors which set the lights at the necessary level of brightness by means of hard-wired logic. There are six fog detectors in the system, distributed as follows: two detectors for section one, three detectors for section two (the middle section), and one detector for section three (the most easterly section). The fog detectors are backscatter devices, and have the capability of sensing five levels of fog density.

An experimental section of 50 low level lights were installed on two entrance ramps. Each light is rated at 500 watts and has louvres to reduce the effects of glare. The lights are spaced 20 feet (6.1 m) on center on the left-hand side of the entrance ramp up to the vicinity of the gore area, where they are placed on 10 feet (3.04 m) centers on both sides of the road. They are mounted under the guard rail and are protected by a chain link fence in front. These lights are also centrally controlled.

Advanced warning of the system's existence is provided by two bulb matrix signs with horizontal louvres that display a black matte face when the lights are not on. When illuminated, the signs read "PAVEMENT EDGE GUIDELIGHTS AHEAD" (Figure E-26). The signs are located 500 feet (152.4 m) in advance of the first inset light for each direction of travel. Each sign is equipped with two amber flashing lights. The two signs are activated whenever the inset lights are activated.

Incorporated into the electrical design of the system is the potential for operating 16 remotely controlled variable message speed signs. These variable signs, of which only one has been installed to date (Figure E-27), are capable of displaying speeds of 15 MPH (24.1 KPH) to 55 MPH (88.5 KPH) in 10 MPH (16.1 KPH) increments, depending upon the density of fog. In any given section, the signs are designed to be controlled by the fog detector recording the heaviest fog. The existing experimental sign is post-mounted at the side of the road. It is diamond shaped, 48 inches (121.9 cm) high and displays the word "FOG" with the speed limit beneath it, and also has the capability of displaying the words "ICE" or "SNOW". As in the case of the advance warning signs, the speed sign has flashing amber lights to attract motorist attention.

The complete system was designed to be activated either automatically or manually, but due to design and equipment difficulties, it is presently being operated manually.

The Virginia Department of Highways is presently engaged in a program to upgrade the operation of the system. The major element of the planned revision is a computer which will automatically control the system guidance lights and signs on the basis of fog and vehicle detector (newly installed) inputs. The computer will also monitor performance and provide fault detection and reporting.

Figure E-26. System Advance Warning Information Sign

Figure E-27. Afton Mt. Variable Message Sign During a Reduced Visibility Condition with Inset Lights On

E5-3 SYSTEM COSTS AND UTILITY

a. COSTS

Implementation, operation and maintenance costs for the Virginia system are shown in Table E-14.

TABLE E-14. VIRGINIA SYSTEM COSTS

Item	Cost (1975)	Cost (1-1-77)
Implementation	$1,845,000	$2,081,000
Operation & Maintenance	$ 16,780*	$ 18,930
Total Present Worth of System	-	$2,302,000**

*Average annual cost after implementation
**Includes the present worth of the operation and maintenance costs projected for 15 years into the future from 1-1-77

b. UTILITY

Table E-15 shows the individual utility ratings for the Virginia system. The total system utility is 433.0 and the utility-to-cost ratio, using the present worth in dollars, as the cost element, is, therefore:

$$\frac{U}{C} \times 10^5 = \frac{433.0}{\$2,302,000} \times 10^5 = 19$$

TABLE E-15. VIRGINIA SYSTEM - UTILITY RATINGS

Utility Measure	System Value	Comp	Util.
I. ROADWAY OPERATION			
1. Reduce Accidents	19.2	5.0	96.0
2. Maintain H/S Level	12.8	6.0	76.8
II. SATISFY PUBLIC DEMAND			
1. Provide Credible A/W	12.6	4.5	56.7
2. Reduce Driver Stress	3.6	5.0	18.0
3. Public Reaction	1.8	7.5	13.5
III. RELIABILITY & MAINTAINABILITY			
1. Reliability	7.5	6.8	51.0
2. Preventive Maint. Reqts	3.7	4.0	14.8
3. Field Maint.	2.3	4.0	9.2
4. Central Maint.	1.5	4.5	6.8

Table E-15. Virginia System - Utility Ratings (Continued)

Utility Measure	System Value	Comp	Util.
IV. SYSTEM OPERATION			
1. Manual Override	3.9	0.0	0.0
2. Operating Complexity	3.9	8.0	31.2
3. Central Control Capab.	3.3	5.0	16.5
4. Backup Capability	1.9	0	0
V. MONITORING CAPABILITY			
1. Traffic Operation	4.5	0	0
2. System Function	4.5	2.0	9
VI. FLEXIBILITY			
1. Ease of Modification	3.6	2.0	7.2
2. Ease of Expansion	2.4	3.0	7.2
VII. SECONDARY USES			
1. Data Processing	2.0	0	0
2. Non-RV Mess. Info.	2.0	0	0
VIII. INSTALLATION DISRUPTION			
1. Service Disruption	1.5	7.0	10.5
2. Installation Complexity	0.8	6.0	4.8
3. Schedule Feasibility	0.7	6.5	4.5
	100.0		433.0

E5-4 MEASURE-OF-NEED

The MON Baseline Data Map for the Virginia system is shown in Figure E-28. The RV accident occurrence is primarily concentrated in MON Section 2 which constitutes 56% of total accident frequency. There is an interchange in this section which causes movements (e.g., weaving) in the traffic that could increase the potential for vehicle conflict when coupled with a fog condition. Table E-16 shows the MON input data. The Virginia system is a Category II system in terms of its AADT traffic volumes. The "before" accident history time period is two years. Although there were no RV fatalities, a total of eight RV accidents occurred during this time period. MON Sections 1 thru 4 are subject to RV on the average of 40 days/year except for Section 5 which experiences 30 days/year. Since the 5.8 mile (9.3 Km) section of I-64 passes through mountainous terrain, the ratings for the geometric index are high, reflecting this characteristic.

The MON histogram for the Virginia system is shown in Figure E-29. As can be seen in the figure, the potential portion of the MON in each section exceeds the medium threshold value. This is due to the frequent occurrence of fog and the roadway's geometric characteristics. The accident portion of the MON is at its high

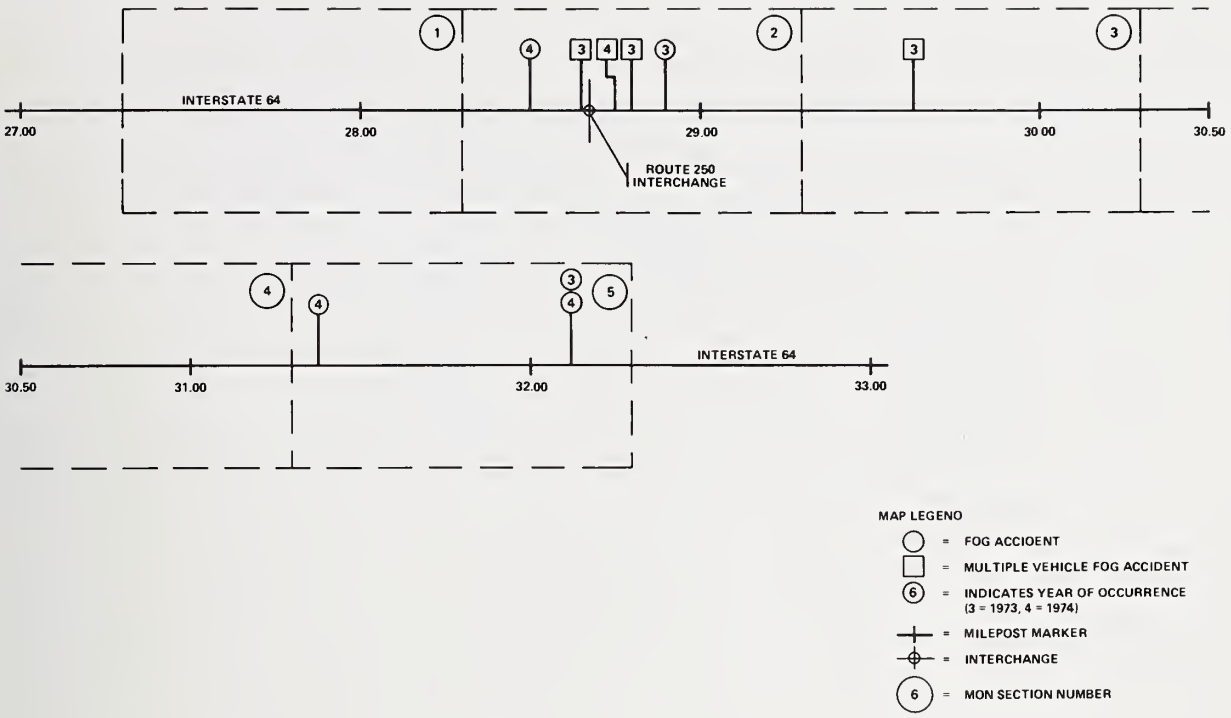


Figure E-28. Virginia (I-64) Afton Mountain System Measure-of-Need MON Baseline Data Map

TABLE E-16. VIRGINIA MON INPUT DATA

VIRGINIA I-64 AFTON MOUNTAIN FILE 24 REV1

#	LENGTH	AADT	YEARS	FATALITIES	MULTI VEH.	TOTAL	RAMPS RV	DAYS	GRADE	CURV
1	1.Ø	99ØØ	2.Ø	Ø	Ø	Ø	Ø	4Ø	4.ØØ	2.ØØ
2	1.Ø	99ØØ	2.Ø	Ø	3	5	4	4Ø	5.ØØ	4.ØØ
3	1.Ø	99ØØ	2.Ø	Ø	1	1	Ø	4Ø	4.ØØ	2.ØØ
4	1.Ø	99ØØ	2.Ø	Ø	Ø	Ø	Ø	4Ø	4.ØØ	2.ØØ
5	1.Ø	99ØØ	2.Ø	Ø	Ø	3	Ø	3Ø	4.ØØ	3.ØØ

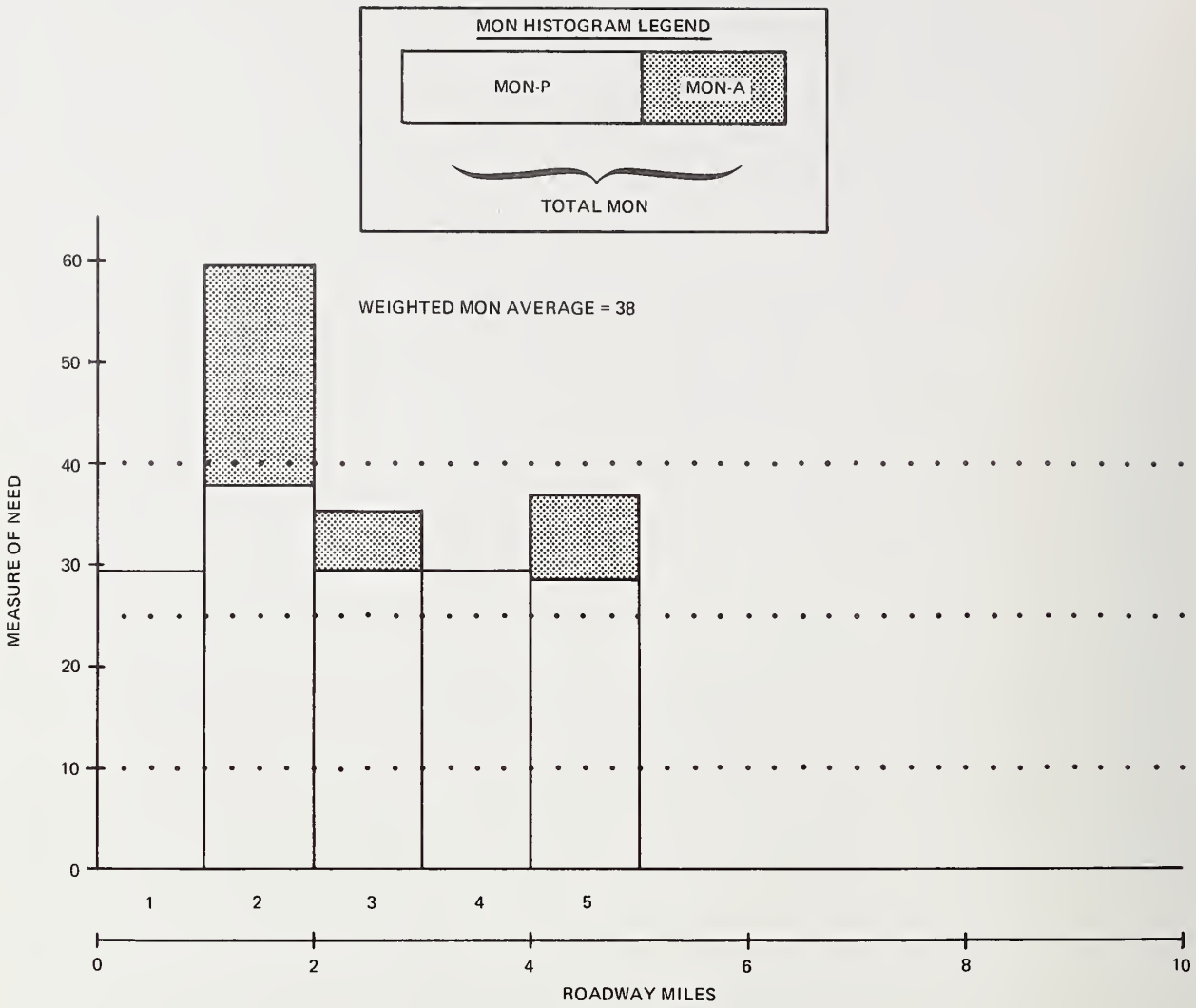


Figure E-29. Virginia MON Histogram

point in Section 2, as to be expected. The weighted MON average for the system is 38, just below the high threshold level. This MON value supports the need for the system in terms of being able to satisfy the intended objectives.

E5-5 DISCUSSIONS

a. OBJECTIVES

The primary objective of the Virginia RV system is to maintain a high level of service on Interstate 64 which is often engulfed by severe but intermittent fog. A secondary objective is to reduce the number of RV accidents over this stretch of the interstate.

b. PERFORMANCE

At the present time, due to some design deficiencies, the system is operated manually. Operational experience has indicated that the location of one of the fog detectors is not optimum. A field study is being performed to identify a more suitable position for the fog detector. The visibility of the two advance warning signs (bulb-matrix type) is limited in a dense fog condition partly because of their size. The speed limits displayed are not always commensurate with the observed vehicle speeds in fog.

Each of the six fog detectors sends an analog signal via hardwired cable to a visibility recorder located in the central control building. The usefulness of these data for control purposes has been limited by a low signal to noise ratio. Automatic operation of the guidance light circuits and variable message signs has not been realized due to excessive "noise" on the communication lines.

Manual control of the system requires that operating and maintenance personnel located some distance from the central building (15-20 minutes) travel to the building, often in fog. Because of the time delay, system operation is not very timely. Additionally, system maintenance requires the inset lights to be activated for longer periods of time than are desirable, resulting in higher maintenance costs.

VDMT is presently engaged in a program to correct these design deficiencies and, thus, insure an efficient automatic operation.

Effectiveness of the system when in operation has been good. In a motorist survey performed by VDHIT, 97% of the people surveyed said that the pavement inset lights either "formed a pattern" for their vehicles to follow or helped in outlining the roadway edges. Approximately 90% indicated that the lights reduced the anxiety of driving in fog. Public reaction to the system has been positive.

c. ECONOMIC JUSTIFICATION

I-64 is the major east-west highway between Staunton, Waynesboro and Charlottesville, Virginia. It is the major commuter link between these cities. Due to the random nature of the fog and to the absence of acceptable alternate routes it is essential, therefore, to keep this highway open at all times.

Since the system was installed, I-64 has not been closed to traffic and the RV accident experience has been extremely favorable. To date, no RV accidents have occurred.

Appendix E-6
WYOMING: I-80 SYSTEM

E6-1. SUMMARY

- Environmental Hazard: Blowing snow
- Site Location: Southeast Wyoming between Laramie and Walcott Junction
- Facility: Interstate I-80; four lane limited access divided highway; AADT = 4,540
- System Length: 60 miles (96.6 km)
- System Elements: Two disc matrix variable message signs, highway advisory radio, snow particle detectors, weather monitoring equipment, control center with sign control computer and associated equipment, 150,000 linear feet (45,720 m) of snow fences and fixed message signs

E6-2. SYSTEM DESCRIPTION

The Wyoming system consists of 3 major independent subsystems. The first subsystem consists of a series of snow fences designed to trap blowing snow and to control drifting snow. (See Figures E-30 and E-31.) The actual length of road protected by the snow fence system amounts to 20 miles (32.2 km). The total length of the fences, which are sometimes arranged in banks of two or three, is 150,000 feet (45,720 m).

In the protected areas, the fences make a dramatic difference. Most of the blowing snow is trapped before it reaches the road, and as a result plowing operations were greatly diminished. In addition, visibility along the road on the downwind side of the fence is greatly improved during blizzards.

The second major subsystem consists of two computer-controlled variable disc matrix signs. (See Figure E-32.) The signs are located at convenient diversion points at each end of the 60-mile (96.6 km) controlled section. Each sign is 8 feet (2.4 m) high by 32 feet (9.7m) wide and is mounted on an overhead sign bridge. Messages are displayed with 18 inch (45.7 m) characters formed by magnetically controlled reflective discs. Each sign contains three rows of display areas with a maximum of twenty characters each. The messages are computer controlled from system headquarters near Laramie. (See Figure E-33.) The characters are magnetically energized from a disc matrix array. Each disc has a high reflective coating on one side for high daytime visibility. At night, luminaires located at the base of the sign are used to illuminate the sign face.

Figure E-30. Wyoming Snow Fence

Figure E-31. Snow Fence with Snow Accummulation on Downwind Side

Figure E-32. Wymoing Variable Message Sign: Reflective Disc Type

Figure E-33. System Control Room Equipment
Left Side: Variable Message Sign Controller and CRT
Right Side: Highway Advisory Radio Broadcast Console

These signs provide warning of high wind, icy road, blowing snow and other hazardous roadway conditions. They can also display arbitrary messages formatted by the operator on a real time basis, e.g. roadway accommodations.

When a hazardous driving condition arises, the radio dispatcher at the Laramie control center will determine the appropriate message to be displayed on the system signs. The code for the desired message is fed by teletype to the sign computer which has a large library of canned messages. The computer retrieves the desired message from memory and transmits the message via leased telephone lines to the signs. If the desired message has been received by the signs, a confirmation is transmitted back to the control center. The displayed message then appears on the cathode ray tube display. Additional messages can be formatted by the system operator. A record of the messages displayed and the time is maintained and is available from the teletype printout.

The third major subsystem is a highway advisory radio (HAR) system. Transmitters are located at a total of four locations; three in the Laramie area and one at the Saratoga Interchange. Three locations have a one-mile (1.6 km) coverage area and the fourth location has an approximate four-mile (6.4 km) coverage area.

The HAR system is designed so that when a motorist travels into one of the areas of radio coverage, a roadside fixed message sign provides instructions for tuning to a specified AM radio frequency for road and travel information. The pre-recorded messages are broadcast at 15-20 second durations.

The four different locations are controlled from one console at the system headquarters. The console consists of a library of pre-recorded tapes and a triple deck tape recorder-player. The console is capable of transmitting different messages to each of the radio transmitters at the same time. Communication from system headquarters to each of the transmitters is by leased telephone lines.

Auxiliary to the three major subsystems are other subsystems used to gather wind, weather and visibility information. One of these subsystems consists of two remote automatic weather detection stations located at Elk Mountain and Arlington. Each weather station is equipped with a specially designed particle counter (Figure E-34) which proivdes data from which the prevailing visual range conditions can be computed. Snow particles passing through the detector generate signal data which is converted into a visibility measure by a small local computer and relayed with wind information from a weather monitoring station (Figure E-35) to a data plotter in the Laramie control center. The data is monitored by the system operator. The Wyoming Highway Department is presently engaged in a program that will integrate the output of these two weather stations into a microprocessor that will select appropriate messages for display on the system variable message signs.

In addition to these two stations along I-80, three mechanical weather stations are in place on alternate route US 30 between Laramie and Walcott Jct. These stations are constantly monitored and compared with the two installations on I-80.

Another weather information service available at system headquarters is the Wyoming weather wire. This is a teletype hookup with the Cheyenne National Weather Service. The State of Wyoming is divided into 12 zones and the National Weather Service provides forecasts for each zone. The forecasts aid in maintenance scheduling and provides advance notice of snow storms.

Figure E-34. Wyoming: Snow Particle Counter

Figure E-35. Wyoming: Weather Monitoring Station

E6-3. SYSTEM COSTS AND UTILITY

a. COSTS

Implementation, operation, and maintenance costs for the Wyoming System are shown in Table E-17.

TABLE E-17. WYOMING SYSTEMS COSTS

Item	Cost (71' to 75')	Cost (1/1/77)
SNOW FENCES		
• Implementation	$ 1,552,000	$ 2,135,000
• Operation & Maint.	---	---
• Present Worth		$ 2,135,000
VARIABLE MESSAGE SIGNS		
• Implementation	$ 250,000	$ 282,000
• Operation & Maint.	$ 6,700/yr.	$ 7,500/yr.
• Present Worth	---	$ 289,500
HIGHWAY ADVISORY RADIO SYSTEM		
• Implementation	$ 150,000	$ 169,000
• Operation & Maint.	$ 11,300/yr.	$ 12,700/yr.
• Present Worth		$ 181,700
WEATHER MONITORING STATIONS (ELK MOUNTAIN & ARLINGTON)		
• Implementation	$ 40,000	$ 45,000
• Operation & Maint.	$ 5,750/yr.	$ 6,400/yr.
• Present Worth		$ 51,400

Assume that the VMS sign and HAR system is used 25 percent of the time for RV conditions due to blowing snow and that the snow fence cost is 100 percent chargeable to reduced visibility use. The total present worth of the system is, then, $2,300,000 which includes the present worth of operation and maintenance costs projected 15 years into the future from 1-1-77.

b. UTILITY

Table E-18 shows the individual utility ratings for the Wyoming System. The total system utility is 546.3, and the utility-to-cost ratio, using the present worth in dollars as the cost element, is, therefore:

$$\frac{U}{C} \times 10^5 = \frac{546.3}{2,300,000} \times 10^5 = 24$$

E6-4. MEASURE-OF-NEED

The RV accidents due to blowing snow on I-80 are displayed on the MON Baseline Data Map shown in Figure E-36. As can be seen in the figure, the RV accidents are basically evenly distributed throughout the 60-mile (96.6 km) section of I-80. MON Sections 7, 12, 18 and 22 contain the largest concentration of accidents. It appears that the two remotely operated weather stations (Elk Mountain and Arlington) have been properly positioned in those sections of I-80 which are frequently subject to RV conditions as indicated by the high accident densities in these areas.

The MON input data is shown in Table E-19. There are 30 MON sections whose lengths vary from one mile (1.6 km) to 5.4 miles (8.7 km). The Wyoming System is a Category I system with AADT volumes that range from 4500 to 4600. The accident history time period covered the winter months of 1974 to 1976. There were no RV accident fatalities; however, accident densities are high on those previously mentioned MON sections. The reduced visibility frequency of 40 RV days per year for all MON sections was estimated from the data gathered by the Wyoming Highway Department and from records of the National Weather Service. It was difficult to differentiate the RV exposure by MON section; therefore, this average value is used in the MON computation process. Since the 60-mile (96.6 km) section of I-80 passes through mountainous terrain, the geometric index for grade was assigned higher than normal value. The horizontal and a vertical curvature on this section is not restrictive, therefore, a low rating was assigned to the curvature index.

The MON histogram for the Wyoming System is shown in Figure E-37. The potential portion of the MON is in the low 20's and is primarily due to the high number of RV days. In comparison to the potential portion, the accident portion of the MON for all the sections is small. This is due to the fact that there were no fatalities and only a few multiple vehicle accidents. MON Sections 15 and 22 have the highest MON values, 32 and 33, respectively. Both of these sections correspond to the two locations of the weather monitoring stations. The weighted MON average is 26, just slightly above the medium threshold value. From the viewpoint of this MON average, the Wyoming System is justifiable.

E6-5. DISCUSSION

a. OBJECTIVES

The primary objective of the Wyoming System is to maintain a high level of service on I-80 for as long as possible during difficult driving conditions. The secondary objective is to divert vehicles to alternate routes in event of road closure.

TABLE E-18. WYOMING SYSTEM - UTILITY RATINGS

	Utility Measure	System Value	Comp	Util
I.	ROADWAY OPERATION			
	1. Reduce Accidents	19.2	6.0	115.2
	2. Maintain H/S Level	12.8	5.5	70.4
II.	SATISFY PUBLIC DEMAND			
	1. Provide Credible A/W	12.6	6.0	75.6
	2. Reduce Driver Stress	3.6	5.0	18.0
	3. Public Reaction	1.8	7.5	13.5
III.	RELIABILITY & MAINTAINABILITY			
	1. Reliability	7.5	7.25	54.4
	2. Preventive Maint. Reqts	3.7	5.75	21.3
	3. Field Maint.	2.3	5.0	11.5
	4. Central Maint.	1.5	7.0	10.5
IV.	SYSTEM OPERATION			
	1. Manual Override	3.9	0	0
	2. Operating Complexity	3.9	7.0	27.3
	3. Central Control Capab.	3.3	7.5	24.7
	4. Backup Capability	1.9	2.0	3.8
V.	MONITORING CAPABILITY			
	1. Traffic Operation	4.5	0	0
	2. System Function	4.5	6.5	29.3
VI.	FLEXIBILITY			
	1. Ease of Modification	3.6	5.0	18.0
	2. Ease of Expansion	2.4	6.0	14.4
VII.	SECONDARY USES			
	1. Data Processing	2.0	3.0	6.0
	2. Non-RV Mess. Info.	2.0	7.5	15.0
VIII.	INSTALLATION DISRUPTION			
	1. Service Disruption	1.5	5.75	8.6
	2. Installation Complexity	0.8	5.75	4.6
	3. Schedule Feasibility	0.7	6.0	4.2
		100.0		546.3

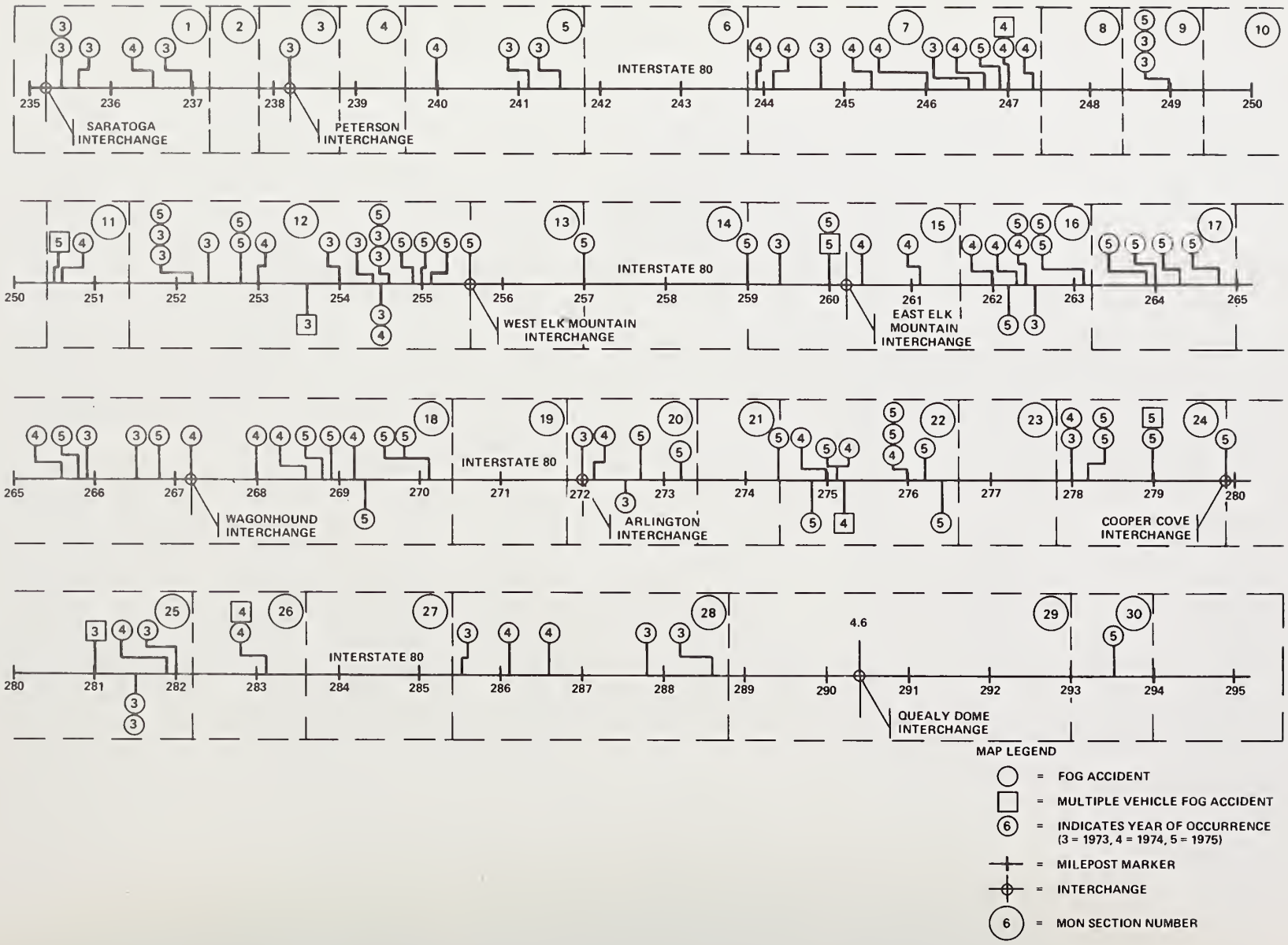


Figure E-36. Wyoming (I-80) System Measure-Of-Need MON Baseline Data Map

TABLE E-19. WYOMING INPUT DATA

WYOMING I-80 FILE 22 REV Ø

#	LENGTH	AADT	YEARS	FATALITIES	MULTI VEH.	TOTAL	RAMPS RV	DAYS	GRADE	CURV
1	2.Ø	45ØØ	3.Ø	Ø	Ø	5	Ø	4Ø	3.ØØ	1.ØØ
2	1.Ø	45ØØ	3.Ø	Ø	Ø	Ø	Ø	4Ø	3.ØØ	1.ØØ
3	1.Ø	45ØØ	3.Ø	Ø	Ø	1	4	4Ø	3.ØØ	1.ØØ
4	1.Ø	45ØØ	3.Ø	Ø	Ø	1	Ø	4Ø	3.ØØ	1.ØØ
5	2.Ø	45ØØ	3.Ø	Ø	Ø	2	Ø	4Ø	3.ØØ	1.ØØ
6	2.Ø	45ØØ	3.Ø	Ø	Ø	Ø	Ø	4Ø	3.ØØ	1.ØØ
7	3.6	45ØØ	3.Ø	Ø	1	11	Ø	4Ø	3.ØØ	1.ØØ
8	1.Ø	45ØØ	3.Ø	Ø	Ø	Ø	Ø	4Ø	3.ØØ	1.ØØ
9	1.Ø	45ØØ	3.Ø	Ø	Ø	3	Ø	4Ø	3.ØØ	1.ØØ
1Ø	1.Ø	45ØØ	3.Ø	Ø	Ø	Ø	Ø	4Ø	3.ØØ	1.ØØ
11	1.Ø	45ØØ	3.Ø	Ø	1	2	Ø	4Ø	3.ØØ	1.ØØ
12	4.2	45ØØ	3.Ø	Ø	1	17	Ø	4Ø	3.ØO	1.ØØ
13	1.4	45ØØ	3.Ø	Ø	Ø	2	4	4Ø	3.ØØ	1.ØØ
14	2.Ø	45ØØ	3.Ø	Ø	Ø	Ø	Ø	4Ø	3.ØØ	1.ØØ
15	2.5	45ØØ	3.Ø	Ø	1	6	Ø	4Ø	3.ØØ	1.ØØ
16	1.5	45ØØ	3.Ø	Ø	Ø	8	Ø	4Ø	3.ØØ	1.ØØ
17	1.8	45ØØ	3.Ø	Ø	Ø	4	Ø	4Ø	3.ØØ	1.ØØ
18	5.4	45ØØ	3.Ø	Ø	Ø	14	Ø	4Ø	3.ØØ	1.ØØ
19	1.4	45ØØ	3.Ø	Ø	Ø	Ø	Ø	4Ø	3.ØØ	1.ØØ
2Ø	1.6	46ØØ	3.Ø	Ø	Ø	5	4	4Ø	3.ØØ	1.ØØ
21	1.Ø	46ØØ	3.Ø	Ø	Ø	Ø	Ø	4Ø	3.ØØ	1.ØØ
22	2.2	46ØØ	3.Ø	Ø	1	11	Ø	4Ø	3.ØØ	1.ØØ
23	1.2	46ØØ	3.Ø	Ø	Ø	Ø	Ø	4Ø	3.ØØ	1.ØØ
24	2.2	46ØØ	3.Ø	Ø	1	7	4	4Ø	3.ØØ	1.ØØ
25	2.Ø	46ØØ	3.Ø	Ø	1	5	Ø	4Ø	3.ØØ	1.ØØ
26	1.6	46ØØ	3.Ø	Ø	1	2	Ø	4Ø	3.ØØ	1.ØØ
27	1.8	46ØØ	3.Ø	Ø	Ø	Ø	Ø	4Ø	3.ØØ	1.ØØ
28	3.4	45ØØ	3.Ø	Ø	Ø	5	Ø	4Ø	3.ØØ	1.ØØ
29	4.2	46ØØ	3.Ø	Ø	Ø	Ø	4	4Ø	3.ØØ	1.ØØ
3Ø	2.Ø	46ØØ	3.Ø	Ø	Ø	1	Ø	4Ø	3.ØØ	1.ØØ

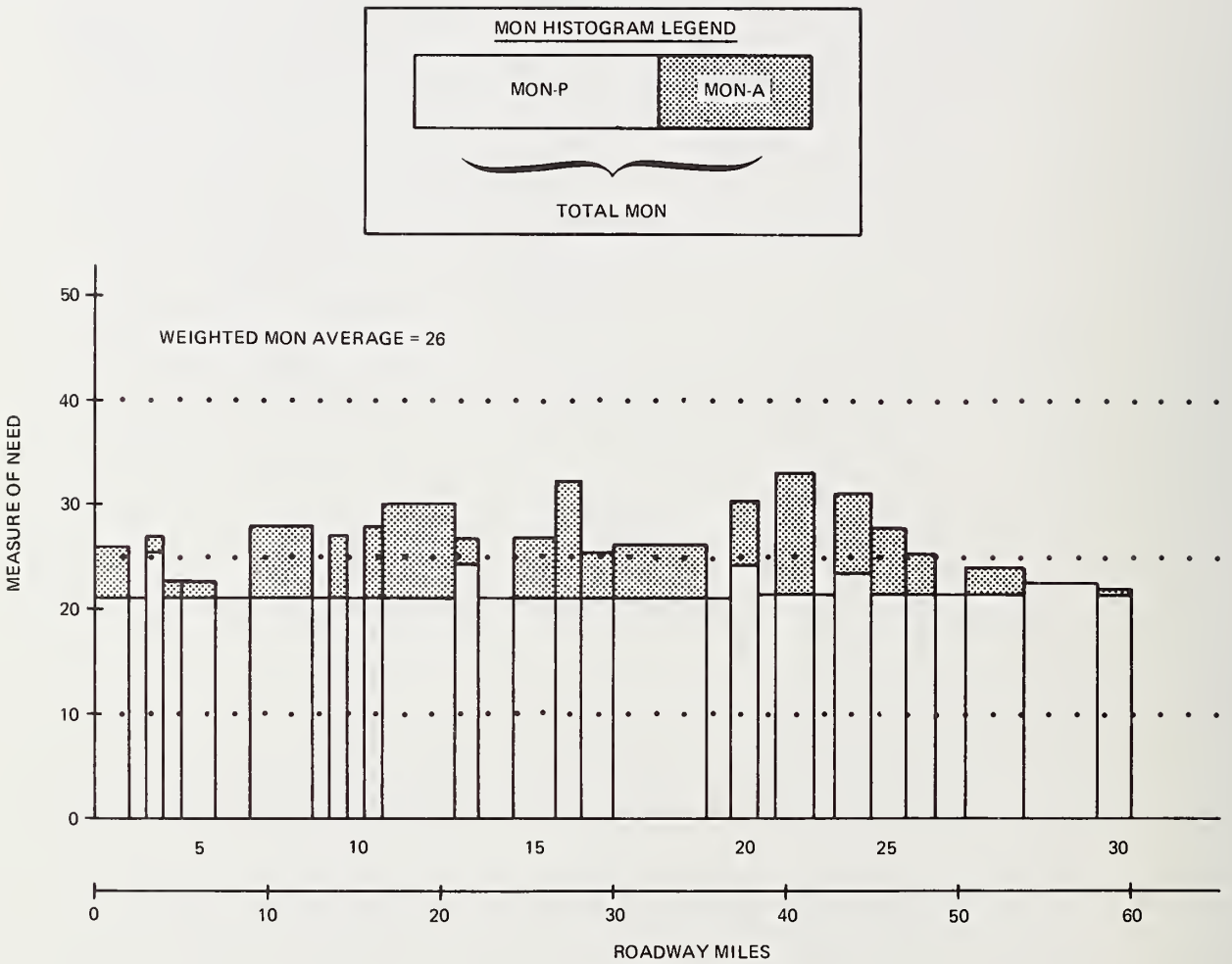


Figure E-37. Wyoming MON Histogram

b. PERFORMANCE

Prior to system installation, snowdrifts often blocked one or more lanes during almost every major snow storm. These snowdrifts left steep snowbanks adjacent to that road, which when coupled with high winds, produced a reduced visibility condition. These problems prompted the Wyoming Highway Department to design and install its present system.

After the snow fences were installed, the Wyoming Highway Department (WHD) collected data over a three-year period to ascertain their effectiveness. Statistical studies indicated a reduction in snow removal cost of 50 percent. During the winter of 1972-73 when precipitation was 130 percent of the estimated long-term mean, protected cut sections of I-80 have remained essentially free of snow drifts. During ground blizzards, dramatic improvements in visibility were noticed downwind of the snow fencing. These results have led the WHD to design an additional 40,000 feet of snow fence for second-priority sites.

In March, 1976, the WHD conducted a Citizens Band radio study to evaluate the effectiveness of the two variable message signs located at either end of the 60-mile (96.6 km) section of I-80. This study was carried out by contacting truckers and other CB'ers on the CB radio to solicit their opinions and comments on the signs and messages. In general, the surveyed motorists had favorable comments about the signs and said that the information displayed was helpful to them.

In another study, the WHD evaluated the effectiveness of the signs and the highway advisory radio (HAR) system in providing road and travel information to the motorist. Evaluation data was collected through motorist questionnaires. Overall, motorists evaluated the variable message sign as an excellent source of road and travel information. The signs were particularly effective as a means of communicating conditions to the nonregional motorists. In comparison to HAR system, the signs were rated consistently better. In general the HAR system was not favorably received by motorists. This negative reaction may have been due in part to operation problems encountered with the HAR field equipment.

From an operational viewpoint, the two signs have been successful. Their reliability has been high and the maintenance experience is normal. On the other hand, the HAR system has suffered from problems with transmission equipment and underground cabling. The weather monitoring stations along I-80 have been operating with satisfactory results.

c. ECONOMIC JUSTIFICATION

The primary justification for establishing the Wyoming system is to maintain I-80 open during the winter months, since it is the major East-West highway across the central portion of the United States. In addition to keeping the highway opened, the snow fences have reduced the local annual snow removal costs. On a 4.6 mile (7.4 km) section of I-80 near Walcott Junction the cost savings amounted to $10,000 per year. Average snow removal cost for the State of Wyoming amounts to 2 million dollars per year. The highway department projected that a well planned state-wide system of snow fences would result in a savings of about one million dollars per year. The snow fences have also improved visibility on I-80 during snow storms.

The system variable message signs have been effective in providing motorists with travel information during adverse weather conditions. In particular, truckers who frequently travel I-80 have benefitted from the adverse weather information provided by the signs. If the conditions on I-80 are poor, (snow or excessive winds) the trucker has the option of taking an alternate route that could save valuable travel time.

The effect of the Wyoming system on accidents has not been determined, because of the variability of weather conditions from year to year. However, it can be inferred that improved visibility resulting from the snow fences has reduced the potential for a RV accident.

E6-6. OTHER REDUCED VISIBILITY GUIDANCE SYSTEMS

The RV systems described and evaluated above are representative of those in the U.S. but do not, of course, exhaust the list of operational systems which it was impossible to study during the course of this program.

Some of these are exclusively for reduced visibility; e.g., the blowing dust system on I-10 in Arizona, near the California border, the automatic fog system over Geneva Marsh near Meadville, Pennsylvania, or the fog system on U.S. 52 near Chillicothe, Ohio. Others, like the sophisticated Hampton-Norfolk bridge and tunnel system on I-64 in Virginia, are designed primarily for vehicle congestion control, with fog as an added feature. Another system of a similar nature is the variable message sign system on I-75, near Cincinnati, Ohio. Its primary function is traffic control during congestion, but it has a manually operated fog capability.

Appendix F

RELATION BETWEEN PROBLEM AREA CHARACTERISTICS AND SYSTEM ELEMENTS

F-1 RELATION BETWEEN PROBLEM AREA CHARACTERISTICS AND SYSTEM ELEMENTS

Possibly the most significant information to emerge from the system evaluation process was the relationship between the geometric, environmental and traffic characteristics of a problem area and the required functions of a reduced visibility system. This relationship was gradually refined over the course of the study and forms the core of the guideline procedure for implementing new systems (Volume I of this report).

Ultimately, a set of fourteen problem characteristics or system descriptors was derived by a process of elimination. Each of the evaluated system locations was carefully examined and a comprehensive list of its characteristics was prepared. The functional elements of the system were then examined to see how they were related to the problem area characteristics. Those characteristics which showed a close relation to functional elements were saved; the others were discarded.

Duplicates were then eliminated from the common set of all important characteristics which could be used to define all reduced visibility system functional elements. This set consists of the following fourteen descriptors:

- AADT category
- Size
- Frequency of patrol (by troopers or other highway department personnel)
- Feasibility of diversion around the problem area, or roadway closure
- Intensity of the reduced visibility problem
- Existence of a reduced visibility problem during daylight hours
- Predictability of the location of the reduced visibility problem
- Predictability of the time of occurrence of the problem
- Need for congestion or incident traffic control
- Need for traffic control during special events

- Need for traffic control during construction or maintenance
- Extent to which transient drivers are a factor in reduced visibility problems
- The importance which is attached to uniformity of speed in the problem area during reduced visibility
- Existence of other weather problems such as ice or snow

Table F-1 shows the relationship between the descriptors and the eight fundamental dynamic elements[1] of a reduced visibility system. These elements are:

- Automatic reduced visibility surveillance
- Dynamic signs (including both the fixed location type and those which are transportable)
- Automatic vehicle surveillance
- Highway advisory radio
- Weather station (surveillance of other weather factors such as ice or snow)
- Broadcast radio
- Active motorist guidance

The nature of this relationship is described in the following paragraphs.

F-2 AUTOMATIC REDUCED VISIBILITY SURVEILLANCE

The problem area characteristics which have the greatest impact on the decision as to whether or not automatic RV surveillance is justified are:

- Size
- Patrol frequency
- Reduced visibility intensity
- Location predictability

Of these, RV intensity and location predictability are the most important. RV intensity must be high; i.e., there must be occasions when visibility drops below

---

[1] Passive delineation, fixed signs, countermeasures and convoys are separately treated elements

TABLE F-1. PROBLEM DESCRIPTORS AND SYSTEM ELEMENTS

Problem Descriptor	Auto RV Surveillance	Dynamic Sign	Transportable Sign	Auto VEH Surveillance	Highway Advisory Radio	Weather Station	Broadcast Radio	Active Motorist Guidelines
1. AADT			X	X				X
2. Size	X		X	X	X		X	X
3. Patrol Frequency	X						X	
4. Diversion/Closure Feasibility					X			X
5. RV Intensity	X	X	X	X	X		X	X
6. Daylight RV Problem								X
7. Location Predictability	X		X			X	X	X
8. Time Predictability			X				X	
9. Congestion/ Incident Control			X	X				
10. Special Events			X	X				
11. Construction/ Maintenance			X	X				
12. Transient Drivers					X			
13. Speed Uniformity				X				
14. Other Weather Factors						X		

300 ft. (91.5 m), otherwise driving conditions do not warrant the use of automatic surveillance. Location predictability is essential for obvious reasons: successful automatic surveillance depends on knowing where to put the sensors.

Patrol frequency is an important factor because the availability of frequent patrols through the problem area may make it unnecessary to use automatic surveillance. This factor is also related to system size and remoteness, since it is less likely that a long and remote roadway will be patrolled frequently enough to supply credible advance warning.

Finally, size or length of the problem area enters into the decision. It becomes less feasible to provide sensors where they are needed as the roadway becomes longer, simply because the costs are so great.

F-3 DYNAMIC SIGNING

The single characteristic of the problem area which affects the decision as to dynamic signing in the most direct way is RV intensity. Dynamic signing is a tool which should not be used unless the reduced visibility intensity is severe; i.e., visual ranges on the order of 300 ft. (91.5 m) or less.

Location predictability is not as important a consideration here as it is for surveillance. For example, there are situations in which manually controlled dynamic signing may be useful for warning in advance of zones where fog may be expected, even though the exact location of the fog may be unknown.

F-4 TRANSPORTABLE DYNAMIC SIGNING

Here, the important characteristics of the problem area which affect the decision are:

- AADT
- Size
- RV intensity
- Location predictability
- Time predictability
- To a lesser degree, the need for traffic control during congestion, special events or construction activities.

Transportable -- that is, truck mounted -- dynamic signing is most useful when the intensity of the RV problem is light or medium and when traffic volumes are not extremely high. Either dense fog or very heavy traffic or both will create a situation in which the trucks cannot be positioned in time to have maximum effect. This is also true if the system is very long.

Time predictability affects the decision because a moderate degree of predictability is necessary in order to get the trucks to their location in time to give adequate help. Location predictability, if very good, argues for automatic surveillance and fixed location signs (except in the case of uniform area-type problems). Thus, the transportable signs are most useful when the location is not so accurately known.

Any requirements which exist for traffic control during congestion, or as a result of special events or construction activity, have a bearing on the transportable dynamic signing decision, since they make it easier to justify the cost of the equipment.

F-5 AUTOMATIC VEHICLE SURVEILLANCE

The characteristics which affect the automatic vehicle surveillance decision are:

- AADT
- Size
- RV intensity
- Congestion/incident control requirements
- Special event control requirements
- Construction maintenance control requirements
- Speed uniformity requirements

Under ordinary circumstances, the use of automatic vehicle surveillance cannot be justified for reduced visibility systems.

There are two quite different sets of circumstances, however, in which automatic vehicle surveillance can be a useful element for reduced visibility. The characteristics which describe these circumstances are as follows:

The first situation is one in which there is a very heavily traveled, high-speed roadway in a densely populated urban corridor. Because of traffic volume and the potential for accidents, a requirement exists for congestion monitoring and control, and for traffic control during special events and during construction or maintenance activities. This requirement is independent of any reduced visibility conditions and, thus, any reduced visibility advantages accruing from vehicle surveillance come almost free of cost.

The monitoring and control in these circumstances is always achieved by means of automatic vehicle sensors, which are part of a fairly complex computerized system. The installation of a system such as this is costly; therefore, it should be seriously considered only for short or medium length roadways, up to perhaps 30 miles (48.3 km) in length.

The second situation in which automatic vehicle surveillance might be seriously considered as a part of a reduced visibility system is one in which it is very important to obtain the highest degree of speed uniformity and credibility in signing possible[1] during very dense reduced visibility conditions. The physical size of the system also affects the decision for the same reason as before; the cost of such surveillance is so high that it should not be considered on any roadway longer than thirty miles (48.3 km).

F-6 HIGHWAY ADVISORY RADIO (HAR)

The problem area characteristics which affect the HAR decision strongly are:

- Size
- Feasibility of roadway closure or diversion
- Reduced visibility intensity
- Fraction of transient drivers

If the RV problem is a serious one -- i.e., visual ranges on the order of 300 ft. (91.5 m) or less at times, and if roadway closure or diversion are feasible alternatives, HAR is a useful element.

The length of the roadway is important, however, because remote locations on a long roadway are difficult and costly to implement with HAR. The most common type of HAR installation is one which is close to a central facility from which messages can be communicated to the local HAR transmitters. The technology for remote HAR transmitters controlled from a central facility does not exist in satisfactory form.

The presence of a significant fraction of transient motorists is also an important consideration. The need for HAR diminishes if most motorists are familiar with the roadway.

F-7 WEATHER STATION

There are two characteristics of importance to the decision on the weather station element:

- Existence of a severe weather problem (e.g., snow or ice or strong winds) in the problem area in addition to any reduced visibility problem it may have

- - - - - -

[1] Automatic vehicle surveillance offers the advantage of being able to set credible advance warning and speed advisory signs on the basis of observed vehicle performance downstream of the sign, in the reduced visibility area.

- Existence of a location at which the weather conditions in the problem area can be determined; i.e., location predictability. This location need not be in the problem area itself, although it usually will be.

The weather station will usually consist of an anemometer and temperature and humidity sensors. In some cases (Wyoming's I-80 system is an example), a snow particle counter may also be present to aid in determining visibility range when blowing snow is a problem.

F-8 BROADCAST RADIO

The problem area characteristics which will affect the choice of broadcast radio as an element are:

- Size
- Patrol frequency
- Reduced visibility intensity
- Location predictability
- To a lesser extent, time predictability

Long problem areas, infrequently patrolled, and with serious RV conditions which can arise at arbitrary and unpredictable points, are best suited to the use of broadcast radio. If any of these conditions is missing, the utility of broadcast radio as a reduced visibility aid is lowered. Location predictability, for example, permits automatic surveillance and signing. Frequent patrols, as another example, provide surveillance which can be used effectively with dynamic signing instead of broadcast radio.

Reasonable time predictability -- within an hour or two -- of the reduced visibility event is a factor in the decision to use broadcast radio. Events which strike without warning and are quickly over do not permit patrol personnel or broadcast stations to be alerted in time to have any effect.

F-9 ACTIVE MOTORIST GUIDANCE (LIGHTS)

The problem area characteristics which most affect the active motorist guidance decision are:

- AADT
- Size
- Feasibility of road closure or diversion
- RV intensity

- Reduced visibility conditions during daylight hours
- Location predictability

The utility of this element is greatest in severe daylight RV conditions -- at night, passive reflective delineation can be very nearly as effective.

The capital costs and the operating costs of active motorist guidance systems are so great that only when there is no alternative route available for motorists, or if service absolutely must be maintained no matter how poor the visibility, can such a system be justified. The problem area must be of limited length, otherwise the cost will be prohibitive.

Finally, the location of the reduced visibility problem must be reasonably predictable, otherwise the lights cannot be placed so as to be effective.

Appendix G

ESTIMATED COSTS FOR NINE MODEL SYSTEMS

G-1 INTRODUCTION

This appendix contains itemized cost estimates for the nine systems which were defined as part of the Systems Definition Task (Task G).

The systems fall into three length categories (point, medium length and long). In each length category, three systems are defined; one for each of three MON categories (low, medium, high).

The costs given in Tables G-1 through G-9 were estimated using the procedures and the unit cost tables in the User Guidelines (loc cit), and the system equipment layouts (Section 3-4 Figures 9, 10, and 11 in this volume).

TABLE G-1. POINT SYSTEM - HIGH MON COSTS

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
1	Raised Pavement Markers, every 20 ft (6.1m) both sides of road in each direction	1,056	9.00	9,504	3,168	-	
2	Post Reflectors, every 20 ft (6.1m) two sides for 1 mile in each direction	1,056	6.00	6,336	-	-	
3	Striping, 8 in (20.3 cm) Beaded Paint both sides and in each direction	4.75 mi (7.64 km)		1,013	2 Yr Life	-	
4	Lamp Matrix Adv Warning Signs (Two lines, Preset Messages w/ cantilevered support)	2	46,000	92,000	2,400	140	
4a	Sign Controller, Limited	1	20,000	20,000	600	-	
5	Lamp Matrix Variable Speed Signs (1 Line)	4	18,000	72,000	2,400	200	
6	Side Mount Support & Structure	4	1,000	4,000	-	-	
7	Flashing Light Assy's	6	500	3,000	90	-	
8	System Cabinet	1	1,500	1,500	-	-	
9	Fog Detectors, Backscatter	3	8,500	25,500	300	-	
10	Special Platform for Fog Det.	3	4,300	12,900	-	-	
11	Vehicle Detectors, Spd Trap Config.	4	1,800	7,200	320	-	
12	Cabinets	2	1,100	2,200	-	-	
13	Ice Sensor System, Complete	2	3,400	6,400	200	-	

Table G-1. Point System - High Mon Costs (Continued)

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
14	Automatic Weather Station	1	5,000	5,000	300	-	
15	Programmable Microprocessor	1	1,500	1,500	150	-	
16	System Development & Programming			15,000	-	-	
17	Communications (TDM) Eqmt.			15,000	500	-	
18	Remote Facility with TTY	1		3,000	-	-	
19	Medium: Radio Communications, 2 Way	11	6,000	66,000	2,000	-	
20	Integration, Testing & Traffic Diversion			26,500	-	-	
21	Design & Engineering			59,447	-	-	455,000

Table G-2. Point System - Medium Mon Costs (Continued)

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
14	Integration, Testing & Traffic Diversion			9,000	-	-	
15	Design & Engineering			34,747			271,000

TABLE G-2. POINT SYSTEM - MEDIUM MON COSTS

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
1	Raised Pavement Markers, every 20 ft (6.1m) both sides of road in each direction	1,056	9.00	9,504	-	-	
2	Post Reflectors, every 20 ft (6.1m) two sides for 1 mile in each direction	1,056	6.00	6,336	-	-	
3	Striping, 8 in (20.3 cm) Bead Paint, both sides and center in each direction	4.75 mi (7.64 km)		1,013	2 Yr Life	-	
4	Passive Signs, 120 sq ft (11.1 m^2)	6	1,000	6,000	-	-	
5	Lamp Matrix Variable Message Sign w/2 lines, Preset Messages, cantilevered Support	2	46,000	92,000	2,400	140	
5a	Sign Controller, Limited	1	20,000	20,000	600	-	
6	Flashing Light Ass'y	2	500	1,000			
7	Fog Detectors, Backscatter	3	8,500	25,500	300	-	
8	Special Platform for Fog Det.	3	4,300	12,900	-	-	
9	Hardwired Microporcessor	1	500	500	50	-	
10	System Development & Programming			10,000	-	-	
11	System Cabinet	1	1,500	1,500	-	-	
12	Communication (TDM) Eqm.			5,000	150	-	
13	Medium: Radio Communication, 2 Ways	6	6,000	36,000	1,000	-	

TABLE G-3. POINT SYSTEM - LOW MON COSTS

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
1	Raised Pavement Markers, every 20 ft (6.1m) both sides of road in each direction	1,056	9.00	9,504	-	-	
2	Post Reflectors, every 20 ft (6.1m) two sides for 1 mile each direction	1,056	6.00	6,336			
3	Striping, 8 in (20.3 cm) Bead Paint, both sides and center in each direction	4.75 mi (7.64 km)		1,013	2 Yr Life		
4	Passive Signs, 120 sq ft (11.1 m^2)	6	1,000	6,000	-	-	
5	Traffic Diversion			5,000	-	-	
6	Design & Engineering			4,147			32,000

TABLE G-4. MEDIUM LENGTH - HIGH MON COSTS

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
1	Raised Pavement Markers, every 20 ft (6.1m) both sides of road in each direction	21,120	9.00	190,080	-	-	
2	Post Reflectors every 60 ft (18.3m) both sides of road in each direction	7,040	6.00	42,120	-	-	
3	Striping: 8 in (20.3 cm) Bead, Sides & Center	110 mi (177 km)		23,460	2 Yr Life	-	
4	Lamp Matrix Advisory Sign, Two Lines Preset Messages with cantilevered Support	12	46,000	552,000	14,400	835	
4a	Sign Controller, Limited	1	20,000	20,000	600	-	
5	Flashing Light Assy	12	500	6,000			
6	Fog Detectors, Backscatter	10	8,500	85,000	1,500	-	
7	Automatic Weather Station	2	5,000	10,000	600	-	
8	Communication (TDM) Eqmt		30,000	30,000	900	-	
9	Medium: Radio Communication, 2 Way	30	6,000	180,000	5,400	-	
10	Cable Installation	1,000 ft (305 in)	22/ft (6.71/m)	22,000	-	-	
11	Minicomputer System Complete w/Map Display			55,000	6,000	-	

Table G-4. Medium Length - High Mon Costs (Continued)

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
12	System Development & Programming			15,000	-	-	
13	Central Facility			5,000	500	300	
14	Integration, Testing & Traffic Diversion			36,000	-	-	
15	Design & Engineering			190,340			1,462,000

TABLE G-5. MEDIUM LENGTH SYSTEM - MEDIUM MON COSTS

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
1	Raised Pavement Markers, every 20 ft (6.1m) both sides of road in each direction	21,120	9.00	190,080	-	-	
2	Post Reflectors every 60 ft (18.3m) both sides of road in each direction	7,040	6.00	42,120	-	-	
3	Striping: 8 in (20.3 cm) Bead, Sides & Center	110 mi (177 km)		23,460	2 Yr Life	-	
4	Passive Signs, 120 sq ft (11.1 m^2)	12	1,000	12,000	-	-	
5	Scroll Sign, Side Mount, Complete	6	23,000	138,000	6,000	130	
5a	Sign Controller, Limited	1	20,000	20,000	600	-	
6	Flashing Light Ass'y	6	500	3,000			
7	Fog Detectors, Backscatter	6	8,500	51,000	800	-	
8	Communication (TDM) Eqmt			13,000	390	-	
9	Medium: Radio Communication, 2-Way	15	6,000	90,000	2,700	-	
10	Cable Installation	500 ft (152.5m)	22	11,000	-	-	
11	Prog'm Proc W. Keyboard Printer			16,000	1,750	-	
12	System Development & Programming			12,000	-	-	

Table G-5. Medium Length System - Medium Mon Costs

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
13	Central Facility			5,000	500	300	
14	Integration, Testing & Traffic Diversion			28,000	-	-	
15	Design & Engineering			98,240			752,000

TABLE G-6. MEDIUM LENGTH SYSTEM - LOW MON COSTS

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
1	Raised Pavement Markers, every 20 ft (6.1m) both sides of road in each direction	21,120	9.00	190,080	-	-	
2	Post Reflectors every 60 ft (18.3m) both sides of road in each direction	7,040	6.00	42,120	-	-	
3	Striping: 8 in (20.3 cm) Bead, Sides & Center	110 mi (117 km)		23,460	2 Yr Life	-	
4	Passive Signs, 120 sq ft (11.1 m^2)	12	1,000	12,000	-	-	
5	Traffic Diversion			15,000	-	-	
6	Design & Engineering			42,340			325,000

TABLE G-7. LONG SYSTEM - HIGH MON COSTS

Item #	System Element	# Reqd	Unit Cost $	Capital Cost $	Annual Maint Cost $	Annual Oper Cost $	Total $
1	Variable Disk Matrix Sign, 3 Line	2	70,000	140,000	2,880	240	
2	Sign Bridge (Installed)	2	60,000	120,000	-	-	
3	Sign Controller	1	50,000	50,000	1,500	-	
4	Rotating Drum/3 Face, Single Drum Sign	28	7,500	210,000	28,000	300	
5	Cantilevered Structure (Installed)	28	20,000	560,000	-	-	
6	Rotating Drum Sign Controller	1	20,000	20,000	600	-	
7	Hwy. Advisory Radio	2	25,000	50,000	5,000	400	
8	Auto Weather Station	1	5,000	5,000	300	-	
9	Communication (TDM) Equip.			30,000	900	-	
10	Medium: Radio Communication, 2 Way	36	6,000	216,000	6,480	-	
11	Thermo Electric Generators w/Fuel Tank Broadcast Radio	17	8,000	136,000 N/C	8,160	-	
12	Minicomputer System w/Map Display			55,000	6,000	-	
13	System Development & Software			15,000	-	-	
14	Central Facility, Moderate			5,000	500	300	
15	Integration, Testing & Traffic Diversion			42,000	-	-	
16	Design & Engineering			240,000			1,898,000

TABLE G-8. LONG LENGTH SYSTEM - MEDIUM MON COSTS

Item #	System Element	# Reqd	Unit Cost $	Capital Cost #	Annual Maint Cost $	Annual Oper Cost $	Total $
1	Rotating Drum/3 Face Single Drum Sign	15	7,500	112,500	15,000	162	
2	Cantilevered Structure (Installed)	15	20,000	300,000	-	-	
3	Rotating Drum Sign Controller	1	20,000	20,000	600	-	
4	Automatic Weather Station	1	5,000	5,000	300	-	
5	Communication (TDM) Eqpt.		16,000	16,000	480	-	
6	Medium: Radio Communication 2 Way	19	6,000	114,000	3,420	-	
7	Prog. M'Proc System w/Keyboard Printer & Map Display			16,000	1,800	-	
8	System Development & Programming			12,000	-	-	
9	Central Facility, Moderate			5,000	500	300	
10	Thermo Electric Generators w/Fuel Tank Broadcast Radio	8	8,000	64,000 N/C	3,840	-	
11	Integration, Testing & Traffic Diversion			24,000	-	-	
12	Design & Engineering			103,500			792,000

TABLE G-9. LONG LENGTH SYSTEM - LOW MON

Item #	System Element	# Reqd	Unit Cost $	Capital Cost #	Annual Maint Cost $	Annual Oper Cost $	Total $
1	Passive Signs, 120 sq ft (11.1 m^2) approx. every 3 miles (4.8 km)	50	1,000	50,000	-	-	
2	Convoy Patrols (4 Patrols in two shifts)	8	30,000	240,000	-	-	
3	Commercial Radio		N/C				290,000

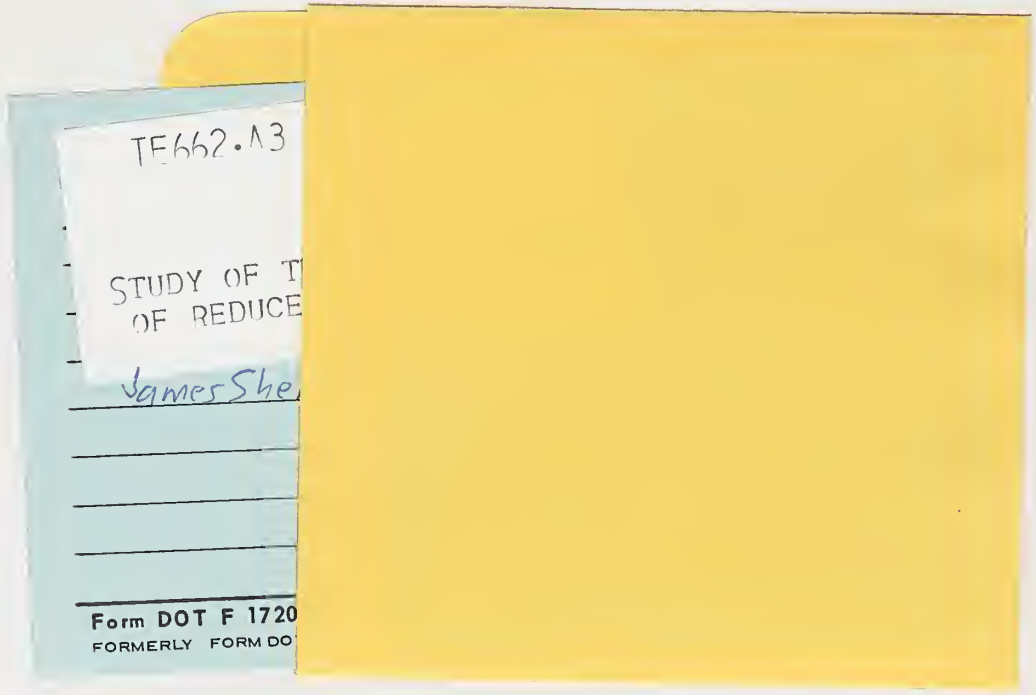
LIST OF REFERENCES

1. User Guidelines for Reduced Visibility Guidance System - FHWA Implementation Package 79-2, April 1979

2. IES Handbook - Fifth Edition, Illuminating Engineering Society, 1972

3. Highway Fog - NCHRP Report 171, 1976

* U.S.G.P.O. 629-695/13022362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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD–2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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